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Hungary

PROSPECTING FOR AND PROCESSING OF BAUXITE

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PROSPECTING FOR AND PROCESSING OF BAUXITE

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1. Bauxite, the raw material of aluminium production

Bauxite is the most important mineral raw material of aluminium, and its significance for aluminium production is fundamental. Since at present aluminium is manufactured almost exclusively from bauxite, it is clear that the importance of bauxite as a mineral raw material increases parallel to the growth of aluminium production. In 1951 aluminium production amounted to 1,99 million tons only, while in 1960 it reached 4,46 million tons. Bauxite production increased similarly during this period: from 10,5 million tons to more than 27 million tons.

The growing demand for, and interest in, aluminium may be explained by the attractive properties of aluminium. It is a light metal /specific gravity 2,7/ of considerable stability, the solidity and corrosion resistance of which can be increased by alloying. It is suitable for casting, rolling, pressing, i.e. rendering it fit for industrial employment within a wide range. It is characteristic of the growing use of aluminium in the industry, that the rate of growth of aluminium consumption has been larger than that of steel; while the annual increase of primary aluminium utilization on a world scale between 1950 - 1960 reached the 14 %, the use of crude steel grew by 6,1 % only. Although the rate of increase of aluminium utilization has been slower since /between 1956 - 1960 the use of primary aluminium showed an annual increase of 6,7 % against the 4,75 % for crude steel/, an average annual increase of 6 - 7 % in consumption can be expected further on /1/. Aluminium is to-day the most important light metal.

The large-scale increase of aluminium production has brought about the corresponding development of prospecting for and research into the raw material. Prospecting is aimed at the discovery of new bauxite deposits in order to augment existing reserves of ore, while research work tries to find technological processes, as will permit the indirect production of aluminium from a non-bauxite raw material. The vigorous geological prospecting of the past one and a half decades has resulted in discovering vast bauxite deposits, e.g. in Guinea, Cameroon, North-Australia, Jamaica, Surinam and, last but not least, in Kazakhstan /Soviet Union/. Although geological exploration in several places has had a preliminary nature allowing only a very rough estimate of the volume of the deposits and the quality of the bauxite, the world's bauxite reserves seem to be significant and sufficient to cover the raw material requirements of aluminium production for long decades.

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1. A. Väth: Stand und Entwicklungstendenzen der Aluminiumindustrie. Metall. /March, 1962/.

Beside bauxite, owing to their high aluminium content, several minerals such as nepheline, leucite, alunite, kaolinite and feldspar may be considered for the production of alumina /Al_2O_3/. Since several large aluminium-producing and consuming countries do not possess sufficient quantities of bauxite reserves of their own, research has been conducted to find rocks ocurring in large masses, and containing one or the other of these minerals to be used as aluminium ore. Methods have been completed for the processing of aluminium-rich clay, high alumina shale in connection with coal deposits, nepheline syenite, alunite and kaolin. These already include such raw materials as are employed economically on an industrial scale; in the Soviet Union nepheline-syenite is processed in a complex way with the addition of limestone, yielding alumina, calcined soda, potash and cement as the end-product. Yet the overwhelming part of alumina is still produced to-day all over the world from bauxite. Therefore the position of bauxite as the most important mineral resources of aluminium production has not changed. It can be expected that this will be so for a long time, since the production of alumina from bauxite is, for the time being, more economic than alumina production from other minerals.

Consequently the bauxite resources represent a considerable economic value and sources of power and, in case of proper utilization, may become an important factor in the economic life of the country. The distribution of the bauxite reserves in the various parts of the Earth is very unequal and the richness in raw material of the countries possessing aluminium industry is very different. A number of large aluminium-producing countries have no bauxite resources of their own, as Canada, Germany, Norway, Japan, Czechoslovakia, Switzerland, or only in insufficient quantities as the United States and Italy. Built and developed on an entirely or overwhelmingly indigenous bauxite basis are among others, the aluminium industries of the Soviet Union, France, China, Hungary and Yugoslavia. Thus several countries are in need of bauxite imports and turn their attention to countries having excess reserves of bauxite and are therefore in a position to export same. Many of the economically under-developed countries - in South America, Africa, Asia - have considerable bauxite deposits. The exploitation of the economic value of these mineral resources is of primary interest to the above-mentioned countries.

2. The occurrences and production of bauxite

Bauxite is a sedimentary rock consisting of several essential and additional mineral components. Its most important essential component is aluminium oxyde hydrate that may be tri- /hydrargillite $Al_2O_3.3H_2O$/, monohydrate /boehmite $Al_2O_3.H_2O$, diaspore $Al_2O_3.H_2O$/, or mixed tri- and monohydrate. A practically constant component is silica that may be found principally in the form of aluminium hydrosilicate /kaolinite, chlorite, etc./, rarely in the form of free quartz.

From an industrial point of view the most important criterion is the quantity and proportion of aluminium oxide and silica. For its numerical expression in most cases the values of base and the bauxite quotient /modulus/ are applied. The base expresses the amount of recoverable alumina, while the bauxite quotient expresses the relation of Al_2O_3 % to SiO_2 %.

Bauxite occurs in very different geologic conditions: in some places there are extensive deposits of several square kilometres, in others again there are lenses filling in the surface depressions of the underlying stratum, or small-sized pockets. Accordingly, the amount of the bauxite material also varies: there are contiguous masses consisting of tens of millions of tons whereas in other places we find only a few thousands or hundreds of tons of bauxite. Within one occurrence, the quality of the rock is as a rule not uniform, since the quality of the bauxite itself varies according to the kind, amount and proportion of the mineral components.

In addition to bauxite, genetically familiar rocks occur as well, such as the bauxitic clay, refractory clay and clay.

The underlying stratum, that is to say the surface on which the bauxite occurrence has developed, is in some places an eruptive rock /mostly basic and intermediary/, in other plees phyllite, shale, clay, frequently limestone and dolomite, rarely sand or other rocks. Bauxite is often sperated from the underlying rock through unconformity, indicating considerable differences in geological age. The geological age of the various deposits may be different, since under suitable terrain and climatic conditions, bauxite may have been formed in different periods of the history of the Earth. Bauxite is known in every continent, except in the Antarctic. The number of its occurrences is extremely high and therefore here we can only mention the most important ones for industry. In Europe the largest deposits may be found in the Mediterranean region and in the Carpathians basin. They have the following geological features in common: the underlying rock is limestone and dolomite, and the bauxite lies in the carstic depressions or cavities of the carbonate bedrock. /2/ As regards their geological age, they are of Triassic, Cretaceous and Eocene origin. The deposits in the counties of Var, Bouches du Rhone and Herault in the South of France, in the region of the Dinari mountains on the territory of Yugoslavia and Greece and in the Transdanubian central mountains in Hungary, are considerable even on a world-wide scale. In the Soviet Union the lower-carboniferous Tikhvin deposits on upper--Devonian clay and sand layers, in the Northern part of the Russian Table are significant. In the Eastern foreground of the North-Ural, the medium-Devonian bauxite deposits of Severouralsk, with their vast reserves, are renowned. The underlying rock is lower-Devonian limestone. In Kazakhsatn large deposits have recently been descovered in the region of the Turgai basin. Here the Cretaceous-Paleocene terrestric formation enclosing the bauxite is deposited on mainly Carboniferous and Devonian limestone and shale layers. Large bauxite deposits of the Carboniferous age have been reported from the Central Kueichou and Central-Yunnan provinces of China, and deposits of the Permian-Triassic age, from the provinces of Central-Shantung, South-Sechuan and South-Liaoning. Significant are the lateritic-type bauxite deposits on hornfels, in the Riau islands of Indonesia. Extensive deposits are known in India on the Cretaceous trap basalt of Dekkan, formed like the Tertiary products of the lateritic weathering of basalt. Of great significance are the lateritic-type bauxite deposits formed on Tertiary strata of clay and sand, discovered during the past decade on the peninsula of Cape York in Northern Australia.

There are rich deposits in Africa, too. The vast bauxite reserves of Guinea deserve to be mentioned; they were formed in the Tertiary, mainly owing to the lateritic weathering of dolerite. The lateritic bauxite deposits of the Adamua plateau of Cameroon cover an enormous area, and very considerable are the similarly lateritic-type Tertiary deposits of Ghana.

The largest deposits of the United States are in Arkansas: they were formed by lateritic weathering in the Eocene on nepheline-syenite basement rock. Much larger are the bauxite deposits of the Carribean region, particularly of Jamaica. Here bauxite is deposited on medium-Eocene-lower-Miocene limestone strata, and is therefore of the carst type. It was formed during the younger Tertiary. In Brazil the lateritic-type bauxite deposits of the Minas Gerais represent large quantities. In some places they were formed on phyllite, in others on nepheline-syenite, in the Tertiary and Quaternary. The deposits of Brit.Guyana and Surinam are similarly of the lateritic type and young in age. Some of them are very significant. Recently a particularly large deposit has been discovered in the Bakhuis mountain of Surinam.

The bauxite reserves of the world are considerable: according to present estimates their total volume may approach 5,000 million tons.

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2. E.Vadász: The geology of Bauxite, Budapest /1961/. In Hungarian.

The exploitation has been going on in many places for various lengths of time. In 1961, the most important bauxite producing countries were the following /3/:

Jamaica	6,2oo million t.
Soviet Union	3,9oo[x]
Surinam	3,353
France	2,182
British Guyana	1,788
Hungary	1,358
Guinea	1,355[x]
United States	1,232
Yugoslavia	1,220
Greece	1,o5o

/x = estimated value./

Only the United States and the Soviet Union process the total of their bauxite production, while the others export a major or minor part of same, and some /Surinam and Greece/, their total production. The yield in Jamaica, Guinea, the Soviet Union, France, Hungary, Yugoslavia and Greece, has shown an increasing tendency during the past few years. In 1961 the total bauxite production of the world amounted to some 27,5 million tons. Its value increased since 1950, according to the Deutsches Institut für Wirtschaftsforschung /4/, in the following way:

1950	Dollars	65 million
1953	"	115 "
1956	"	139 "
1957	"	151 "
1958	"	166 "
1959	"	180 "

In most places of occurrence, bauxite is produced by opencast mining. There are, however, underground mines aswell: in the United States, France, Hungary, Yugoslavia and of particularly large capacities in the Soviet Union. Hungary obtains 67 % of her bauxite yield, from underground mines.

Considering a further increase in demand and production and owing to the gradual exhaustion of the existing mines, new occurrences will have to be initiated for cultivation. It is therefore necesaary to make provisions for suitable bauxite reserves.

3. Bauxite exploration

The prospecting for raw materials of mineral origin usually starts within the frame of general, geological mapping. Concerning the dimensions of the mineral occurrence, the quantity and quality of its reserves such prospecting generally yields approximate data which may be used for initial economic estimates only. The full extent and value of the occurrence of a mineral raw material can, in the first place, be learned by an appropriate geological exploration aimed explicitly at the desired mineral. It is chiefly in this way that the instruments, methods, material-testing processes, best suited to the geological conditions and to the mineral-petrological characteristics of the mineral material, as well as the experts may suitably be chosen to ensure fast and efficient work.

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3. Mining Journal. Annual Review /1962/
4. Revue de l'Aluminium. No. 294 /Oct. 1961/.

The prospecting for, the preliminary and detailed investigation of, bauxite occurrences should be undertaken within a specialized exploratory program performed partly by big private enterprises, partly by State institutions or enterprises. The explorations, for instance, in the Northern--Ural bauxite regions of the Soviet Union and also in Hungary, are conducted by State enterprises formed for, and specialised in, bauxite research.

In the interest of speeding up the acquisition of information and of increasing the efficiency of operations, it is advisable to conduct the research work step by step: in the first stage, comprising prospecting, the places of occurrence should be ascertained; in the second stage - preliminary exploration - the occurrences already established are outlined and approximate information is gained on the reserves. In the third stage, which may be called exploration in detail, the occurrence should be thoroughly investigated and the quantity and quality of the reserves should be estimated accurately. Naturally, in the various fields of exploration, work may reach simultaneously different stages. In the course of work the principle of complex execution should be enforced even in the case of specialized prospecting for a raw material of mineral origin, that is to say, the other mineral materials appearing in the course of the prospecting operations should also be considered and assessed. It is advisable to classify the various fields of exploration according to their dimensions and economic significance, to carry out the work of prospecting in the various fields, in such a succession as will permit the acquisition of the optimum geological information and to explore the places of occurrence in accordance with the economic value that may be expected of them. The work of prospecting should have a sound economic foundation and the amount spent on exploration should be in proportion to the results obtained.

The generally employed means of bauxite exploration are the geological mapping, sinking of trenches and pits, manual and mechanical drilling. The scale of the geological mapping, further the density applied in the location of trenches, pits and drillings should always conform to the stage of exploration in order to obtain a proportional amount of geological data. In the course of the preliminary and detailed exploration, the pits or drillings are located according to a regular pattern. In the case of exploration by drilling, it is advisable to employ core drilling for the cross-cutting of the totality of the bauxite, in order to obtain a proper quantity and quality of rock material available for the chemical and technological tests.

In several instances geophysics may be employed with advantage for bauxite prospecting, principally through electric, magnetic and seismic measurements. These geophysical measurements are aimed, in most cases, not at the material establishment of the bauxite, but at the detection of such structures or layer succession, as are generally connected with bauxite occurrences. The material confirmation of the bauxite itself is the task of the geological prospecting following geophysics. Refraction seismic measurements have successfully been applied in Arkansas /USA/, and vertical electric sounding and magnetic measurements in Kazakhstan /USSR/.

The quality of bauxite is ascertained by chemical, mineral-petrological and technological tests. These determine its chemical and mineral composition and the method and extent of its industrial utilization. The chemical analysis is completed either in the wet way or by spectroscope. The mineral components are established partly in an optical way and partly by the differential thermoanalysis, thermogravimetry, and X-ray methods usually employed in clay--mineral investigations. The technological investigations consist mainly of digestion, in order to determine the amount of the available alumina.

In some places bauxite prospecting also demands hydrogeological investigations, since some bauxite deposits are connected with subsurface water

and considerable water invasion may appear in the course of mining.This is frequent particularly in carst-bauxite deposits situateddeep under the surface and under the regional carst-water level of the area. Such occurrences prevail in the North-Ural and in certain bauxite areas of Hungary. For this very reason in these places, bauxite prospecting is accompanied by energetic hydrogeological investigations.

Following the determination of the extension and thickness of the occurrence, as well as the volume weight and quality of the bauxite, the qualitative classification of the reserves and the calculation of the quantity can be effected. The classification of the bauxite by quality is a function of industrial requirements and varies greatly in the individual countries. In various countries the quality is determined by industrial norms.

The accuracy of the reserve estimation depends on the amount and reliability of the data available. In view of the fact that a useful economic and industrial evaluation can only be effected on the basis of precise and reliable reserve-data, the particulars regarding the reserves are, as a rule, rated in order to indicate the degree of accuracy and reliability. In the United States the terms "measured", "indicated" and "inferred", are applied for this purpose. The Soviet Union and several other countries, including Hungary, express the extent to which investigation of the reserves has been completed and the degree of reliability of the data by the so-called category indication. These categories are as follows: A, B, C_1 and C_2 of which A indicates the maximum extent and C_2 the minimum extent of investigations completed. In addition, category D is used to indicate inferred reserves. In general a mine can only be settled for reserves qualified in their majority by A+B+C_1.

The data of geological exploration of a suitable extent serve as a basis for the assessment of the economic value of individual occurrences or of whole bauxite areas.

4. Processing

The most important phase of bauxite processing is the production of alumina, from this the production of aluminium, and to a small extent, the production of cement, abrasives, paint and filter materials. Here we wish to deal only with the most important phases: the production of alumina and of aluminium.

a./ The production of alumina. Alumina is usually obtained by the Bayer, and the soda-lime sintering processes, further by the parallel and series--combined process developed from the coupling of the two. At present some 75 % of the world's alumina production is obtained by the Bayer process. For the processing of high-quality bauxite with low silica content, mostly the Bayer process is used, while for poor-quality bauxite with considerable silica content, the sintering or the combined processes are employed. For the production of 1 ton of alumina, 2-3 tons of dry bauxite are necessary, depending on the quality of the bauxite. With the Bayer process, the aluminium-oxyde-hydrate content of the bauxite is digested by a caustic soda solution, then the solution obtained in this way and rich in sodium-aluminate is diluted and allowed to settle, so that the red mud should separate. The retained pure solution is cooled and the aluminium-hydrate separated in precipitation tanks by way of hydrolisis, then it is heated to alumina. The digestion of the pure trihydrate bauxites is possible at atmospheric pressure, therefore their digestion requires less thermal energy and generally lower costs than in the case of the monohydrates. With the soda-lime sintering process the ground bauxite, the soda and the limestone are blended and heated to calcine at a high temperature /1,100 - 1,300 C°/, in consequence of which the aluminium-oxyde content of the bauxite will be transformed into natrium-

aluminate to be extracted from the calcine. Thereafter the hydrate may be segregated from the solution containing natrium-aluminate, through treatment by carbon dioxide or by stirring. The investment and working costs of the sintering process are higher than those of the Bayer process, the contamination of the alumina by silica is higher, therefore it is applied for the processing into alumina of such bauxites only, as have a significant silica content /7 - 12 %/ and consequently, in case of employing the Bayer process, high and expensive caustic soda losses would occur. The volume of the alumina produced by the pure sintering process amounts only to some 5 % of the world's total production.

Another method for producing alumina is the combination of the Bayer and the sintering process. With the parallel-combined process good-quality bauxite will be digested in the Bayer branch and poor-quality bauxite in the sintering branch, and the caustic soda loss of the Bayer branch will be supplemented by the natrium-aluminate that will be formed out of the soda employed in the sintering branch. For the economy of the process, the capacity of the two service branches should be so dimensioned as to permit the soda application of the sintering branch just to supplement the caustic soda loss of the Bayer branch.Consequently with this process of alumina production, some 80 - 85 % of the production will be on the Bayer service branch. The process is more widespread than pure sintering and is employed principally in the Soviet Union and in Italy. It accounts for about 13 - 15 % of the world's alumina production.

With the series-combined process, generally the poor-quality, bauxite with high silica content isworked up: at first the material is treated according to the Bayer method, then the red mud still containing a relatively large quantity of aluminium oxide is digested by the soda-lime sintering process. In thisway the loss of caustic soda is smaller than in case of the Bayer process, the thermal-energy requirement is smaller than with the pure sintering process, yet the alumina yield will be still favourable. The process is employed, according to our knowledge, in the United States, and the alumina obtained in this way, accounts for 5 - 5,5 % of the world production.

In addition to the methods of alumina production mentioned in the foregoing, several other patented methods are known, yet only a few of them have found employment in the industry.

The by-products of alumina production may partly be utilized; for instance, the iron content may be recovered from the red mud formed in the course of the Bayer process, and vanadium and gallium are selected in Hungary from the salts. Approximately 90 - 91 % of the world's alumina production is used for the manufacture of metal aluminium, hence, on the whole, an equilibrium has been established on a world scale between the alumina--producing capacities and those of the aluminium plants, although in several places the location of the alumina-producing plants does not coincide with that of the aluminium plants. Namely transport expenses will work out in the most favourable way, if the alumina plant is settled near the bauxite base and the aluminium plant near the power works, if this is possible at all. For this reason the tendency is to place the alumina plants as close, as possible to the bauxite mine and the aluminium plants near the power source. Such requirements have recently been met when building the alumina-producing plants in Jamaica and Guinea. According to G.A. Baudart /5/, relying on the situation in June 1960, the alumina capacity of the West is estimated 830 thousand tons higher than the amount of alumina required to meet the smelting capacity, and the actual equilibrium may be ascribed to alumina consumers

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5. G.A. Baudart: Étude systématique de approvisionnements en alumine dans le monde en 1960. Revue de l'Aluminium No.284./Febr.1961/.

other than the aluminium plants. The supplies of alumina available in the consuming countries varies greatly; in some places there is a shortage, in others again an excess, which accounts for the lively international trade in alumina. In view of the above-mentioned requirements to be met in settling alumina and aluminium plants, a significant alumina trade is to be expected also in the future. The highest alumina capacities exist at present in the United States, the Soviet Union and Canada.

b./ The production and utilization of the aluminium. Aluminium is produced through the electrolysis of alumina /Al_2O_3/ between carbon electrodes in a cryolite melt, under the use of about 1,9 specific alumina and a large amount of electric power. Hence the provision of the required electric power is a primary condition of aluminium metallurgy. The specific consumption of direct current in the average furnaces is of the order of 16 - 17,000 kWh/1 t of aluminium, and even in the up-to-date furnaces operating with high current intensities /80,000 - 100,000 amperes/, it is 14,500 - 15,000 kWh /6/. This accounts for the fact that economical primary aluminium production is only possible where a large quantity of cheap electric power is available.

Formerly aluminium metallurgy used exclusively cheap energy obtained from hydroelectric power stations, while in the course of the last three decades, power produced by the thermal power stations has become competitive. Unlike hydroelectric power stations, thermal power works possess the advantage, that their current supplies are uniform throughout the whole year, while the current supplied by hydroelectric power stations changes periodically, depending on the water supplies.

The thermal power stations working for aluminium metallurgy utilize black coal, brown coal or natural gas as fuel. Recently the smelter capacity produced by thermal power has increased particularly in the United States: by the end of 1961, the capacity of aluminium plants operating on hydroelectric power has amounted to 1,154,000 tons, while that of the aluminium plants operating on thermal power amounted to 1,296,000 tons /7/. The overwhelming majority of aluminium plants of the world, however, still employ electric power obtained from water power stations and plants are still settled economically on a hydroelectric power base as shown by the recent establishment of the aluminium plant in Cameroon and by the plan for building a vast smelter in Ghana /with an end-capacity of 210,000 tons/ within the so-called Volta project.

According to preliminary figures, the world's production of primary aluminium in 1961 amounted to 4,446,000 l.tons./3/. This is the participation of the most important countries /in thousands of l. tons/:

United States	1,700	Italy	82
Soviet Union	740	China	80
Canada	580	Austria	67
France	275	Hungary	50
Norway	170	Poland	47
German Federal Rep.	170	Cameroon	45
Japan	147	Switzerland	41

The chief aluminium-consuming countries are the United States, the Soviet Union, Britain, the German Federal Republic, France, Japan, Canada.

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6. H. Schmitt: Neue Gesichtspunkte beim Bau von Aluminium-Elektrolysenöfen. Zeitschrift für Erzbergbau und Metallhüttenwesen. No. 9. /Sept. 1961/.
7. E. Rauch: Hydroelektrische und thermische Energie in der Aluminiumherstellung. Metall /March, 1962/.

Aluminium being an important industrial raw material very much in demand a significant part of primary aluminium is handled by international trade.

In 1960, for instance, nearly 25 % of the world's primary aluminium production was exported. According to G.A. Baudart, the principal exporting countries in 1960 were the following /8/:

Country	Export in % compared to production	Participation of the country in %, of world exports.
1. Canada	72,5	44,3
2. United States	14,1	22,9
3. Norway	83,5	12,2
4. France /including Cameroon/	29,6	7,2
5. Soviet Union	8,5	6,0
6. Austria	32,0	1,9
7. Others	2,4	5,5

The number of countries importing primary aluminium is very high: the most important ones are Britain, the German Federal Republic, the United States, Belgium and Italy.

The industrial utilization of aluminium is manifold, and the fields of its employment widen all the time: transport and the production of vehicles, building industry, electrical engineering, machinery and apparatus manufacture, food and packaging industry, metallurgy of non-ferrous metals and powder metallurgy, chemical industry, the manufacture of utensils and household articles and mass products.

According to statistics compiled by A. Väth, aluminium consumption in the West in 1960 was as follows: /1/

Transport	18,5 %
Building industry	17,0 %
Electrical engineering	12,2 %
Packaging	7,9 %
Production of machinery and apparatus	7,8 %
Metallurgy, powder-metallurgy and desoxidation	4,4 %
Others	32,2 %
	100,0 %

Of course, in the various countries the extent of utilization is very different, in accordance with the demands of consumption and the industrial advancement of the particular country.

In certain economically and industrially developed countries the per capita consumption has already reached 5 - 10 kg/capita, however, on a world scale the average is 1,5 only. On the basis of growing aluminium consumption,

8. G.A. Baudart: Les grands courants de l'aluminium dans le monde. Revue de l'Aluminium No. 294 /Jan. 1962/.

it may be inferred that by 1970 the consumption will have reached the value of 2,7 kg/capita /9/.

5. The possibilities of utilizing bauxite resources and the respective assistance.

The profitable exploitation of the bauxite resources depends on the economic strength, industrial development, power sources of the respective country, further on the requirements of home consumption and its capacity of absorbing the goods, and finally on the chances of export. Bauxite can be sold as an ore abroad or can be processed inland and the product so obtained, sold on the home or foreign markets.

An economically underdeveloped country can easiest develop bauxite production, since this claims little investment, few means of production, and a relatively small number of technically trained personnel, particularly in the case of openeast mining. From the point of view of transportation, marketing and employment, it is of advantage to couple the production of bauxite with the manufacture of alumina, yet here substantially larger investments and a higher degree of technical preparedness will be required. In possession of rich power resources, principally hydroelectric power, water power station and the building of an aluminium plant close to it, may already be considered. This requires considerable investments, particularly the building a hydro-electric power station. In under-developed countries the production of half-finished or finished aluminium ware is generally established in accordance with the requirements of home consumption.

The efforts aimed at the utilization of bauxite may be different in the various regions, depending on natural conditions and the degree of exploitation. In some of the under-developed countries, bauxite production may already have reached considerable proportions, yet they may have no or only an insignificant alumina production. This is the situation prevailing in certain countries of the Carribean area, where efforts are made to develop a corresponding alumina production capacity, based on their own bauxite resources. In other areas again as for instance in some West-African countries, even the production of bauxite is low as compared to the existing possibilities. Here, considering the natural endowments, not only vast bauxite production and manufacture of alumina could be developed, but the production of aluminium could be based on hydro-electric power. This was started in Guinea, Cameroon. Nor have the rich bauxite resources of several other areas been sufficiently exploited.

The production of bauxite and the establishment of an industry for processing demands proper engineering skill and equipment as well as capital, which in the case of an under-developed country may not be available. The technical and economic aid to be offered by the advanced countries is therefore a necessity. Their assistance may consist of sending or training experts, of making engineering or economic plans, of placing at their disposal means of production or transportation, of the offering of credits or of other financial aid. In this way the bauxite resources not yet utilized, or not satisfactorily utilized in several countries may be exploited . Thereby new centres of the aluminium industry will be created in areas with vast bauxite resources, and included in exploitation to satisfy the growing consumption of aluminium. In this way assistance will become mutually profitable.

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9. Revue de l'Aluminium, No. 283. /Jan. 1961/.

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SUMMARY

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of alumina. Since some 90-91 % of the world's alumina production is used for the production of aluminium, an equilibrium has been established on a world scale between the alumina and aluminium plant capacities, although in many places the geographical location of the alumina and aluminium plants does not coincide. On account of the costs of forwarding, the tendency is to locate the alumina plants as near as possible to the bauxite deposits and the aluminium plants near the power source. At present the United States, the Soviet Union and Canada possess the highest production capacities for alumina.

Aluminium is produced by the electrolysis of the alumina /Al_2O_3/ between carbon electrodes in melt of cryolite, with the utilization of approximately 1,9 specific alumina and a large amount of electric power. This is why an economic primary aluminium production is possible only in places, where cheap electric power is available in large amounts. The electric power supplies come mostly from hydroelectric power plants and to a smaller extent from thermo-electric power stations. According to preliminary figures, the world's primary aluminium production in 1961 amounted to 4,446,000 long tons, with the United States, the Soviet Union, Canada, France, Norway, the German Federal Republic, Japan, as the principal aluminium-producing countries.

The industrial utilization of aluminium is of a rich variety and the fields of employment extend all the time. Aluminium is utilized in transport and the manufacture of vehicles, in building industry, electrical engineering, in the manufacture of machinery and appliances, in the food and packaging industries metallurgy of non-ferrous metals, the chemical industry, manufacturing of pans and other household utensils, as well as of mass products.

For economically under-developed countries the realization of bauxite production presents the least difficult problems, since it involves relatively little investment and equipment for production, further only a small number of technically trained personnel, particularly in the case of opencast mining. From the point of view of transport, marketing and employment, it is advantageous to link up the production of bauxite with the production of alumina. If rich sources of power are available, the building of an electric power plant and, next to it, of an aluminium smelter, can be considered. In under-developed countries the production of half-finished or finished aluminium ware is generally established in accordance with home consumption.

For utilizing its bauxite resources a country with a poorly developed economy may possibly require the technical and economic assistance of the developed countries, such as the delegation or training of experts, the completion of engineering and economic plans, means of production and transportation, credits or firancial aid.

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UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: D.8.2

Norway

ELECTRIC SMELTING OF IRON ORES FOR LESS DEVELOPED AREAS

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1. INTRODUCTION

The dominating position of iron amongst metals has found expression in technical terminology: We talk about "ferrous" in contrast to "non-ferrous" metallurgy.

Production statistics also indicate that we still live in "The Iron Age". The world's annual production of pig iron is approximately 250 mill. tons, while the production of aluminium, copper and zinc is in the order of 5 mill. tons a year each - i.e. 2% of the iron production.

All the big industrial countries have well established iron and steel industry. It might be said that the status of iron metallurgy in a country expresses its industrial potential.

The traditional furnace type for production of liquid pig iron from ore is the blast furnace. Already before the last World War blast furnaces were developed to very large units and adopted by the larger steel works around the world.

Important progress in the blast furnace operation has been achieved by means of pretreatment of the raw materials in the sinter works. In U.S. and Europe, as well as in Japan, the capacity for sintering ore fines and concentrates has been increased. Based on pioneer work at Domnarvet in Sweden, many blast furnace plants are producing a self-fluxing sinter, i.e. sintered iron ore, including the fluxes. This type of sinter reduces the carbon as well as the energy requirement in iron ore smelting both in the blast furnace and in the electric furnace.

The average capacity of the 266 blast furnaces in operation in U.S.A. per January 1st, 1959, was 960 tons. In Western Germany 127 blast furnaces were in operation in 1961 - average daily production 550 tons. Approximately 1000 tons per 24 hours appears to be a typical production capacity for new blast furnaces. Recently, three integrated iron and steel works have been erected in India, each with a capacity of approximately 1 mill. tons of steel per year. All these works are equipped with blast furnaces designed for a production of approximately 1000 metric tons per day.

There are a few very big blast furnaces with a production capacity of up to 2000 tons.

Large production units facilitate mechanization of the handling of raw materials, etc. and contribute to a reduction of the number of labour hours per ton of pig iron. For the very large blast furnaces the labour requirement is only a fraction of one hour per ton.

Despite the impressive size and efficiency of the blast furnace, this type of pig iron production unit has met with considerable criticism over the last decade. Extensive research and development work has been carried out to investigate alternative methods for obtaining iron from iron ores. One of the main reasons for these efforts has been the fact that the large blast furnaces establish very strict specifications for the size and mechanical strength of the coke.

Coal suitable for the production of high quality coke is required. These good coking coals are not available everywhere, even in countries with extensive coal resources.

2. OFF-GRADE COAL

The electric pig iron process was originally based on the use of a mixture of lumpy coke and coke breeze. A majority of the plants are using gas works coke, but in some cases a mixture of coke and anthracite is being used. The electric pig iron process is now developed for the use of raw coal such as baking coal, non-coking coal, lignite, etc. The volatiles in the coal are utilized in the process for preheating of the charge and prereduction of the ore.

There are also ores which cannot be smelted in blast furnaces - the so-called titaniferrous iron ores containing about 10% TiO_2 which gives operational trouble with deposits of titanium-carbides and - nitrides in the blast furnace shaft.

The electric smelting of TiO_2-containing iron ores was first developed in Norway and later in Japan. The expansion of electric pig iron smelting in Japan is based on the use of one of the very few domestic resources of iron ore, the beach sand concentrates. This sand is concentrated magnetically to 55 - 60% Fe and 8 - 12% TiO_2, sintered and smelted in electric pig iron furnaces.

Low-grade iron ores which are not amenable to ore-dressing and concentration are uneconomical to smelt in blast furnaces due to the unreasonably high coke consumption. In many of the industrially less developed areas a situation prevails where one or more of the basic factors required for the blast furnace process are missing. Iron ore of the type suitable for blast furnace burden will have to be imported from abroad, or transported over long distance, or only low-grade coal, non-coking coal, lignite or brown-coal are available. In quite a few of the new steel countries electric pig iron smelting has been adopted and solved the problems of pig iron production from raw materials unsuitable for the blast furnace.

3. DESIGN FEATURES OF ELECTRIC PIG IRON FURNACES

Figure I gives a vertical cross section through an ELKEM pig iron plant. The charge is distributed to the furnace bins by transport with skip-hoist and telpher bucket. From the bins above the electric furnace the charge flows by gravity through the chutes to charge openings in the roof, and keeps the electric furnace automatically filled with charge.

All the furnaces which have been built by Elektrokemisk during the last ten years are equipped with circular furnace pots and three Søderberg electrodes arranged in delta formation. Below each electrode considerable quantities of coke float in the slag, the so-called coke bed, which constitutes an important element in the smelting process. The electrode current passes from the electrodes through the preheated part of the charge, which is conductive to electricity, and then through the coke bed and the slag. The main reaction as well as the fusion of the charge takes place in the vicinity of the electrode tips where the liberation of electric energy is most extensive. As the height of the charge above the smelting zone is relatively low and the quantity of gas is considerably smaller than in blast furnaces because no air is blown in, relatively little preheating and CO reduction take place in the electric furnace, except with a specially prepared, porous charge.

As for blast furnaces, iron and slag are tapped from a tap hole near the furnace hearth. Reaction gases are sucked off from openings in the furnace roof,

scrubbed with water and distributed to gas holders and the gas distribution system.

The pioneer furnace for closed operation with collection of unburnt CO-gas was developed by the Norwegian engineers Tysland and Hole at Christiania Spigerverk at the outskirts of Oslo. This furnace was in operation from 1923 to 1947 under inspiring leadership of Mr. Gunnar Schjelderup. Table 1 presents a list of electric furnaces of Tysland-Hole - ELKEM type in operation or presently under construction.

The total furnace capacity installed and ordered per September 1st is abt. 775 MW.

In this table are not included furnaces for abt. 150 MW built by other furnace manufacturers. In addition also comes a number of small furnaces built after the war in Japan.

4. ELECTRIC PIG IRON SMELTING TO-DAY.

Only a short description will be given here of the latest electric pig iron furnace installations.

Christiania Spigerverk acquired a smelting plant at Bremanger in Western Norway in 1952. Here a 33 MVA electric furnace and a new sintering plant was installed in 1959. This furnace is in production on a special grade titanium and vanadium bearing pig iron.

An important and courageous step was taken by A/S Norsk Jernverk just after the war, in their decision to instal three electric pig iron furnaces, later supplemented with a fourth furnace unit, each with 33 MVA transformers. This state-owned plant in Mo i Rana, just below the Polar Circle, has been in continuous operation since 1955. The yearly production is now abt. 360.000 metric tons, partly for the company's own steel works and partly for sale.

Typical data for the present operations are as follows:

Furnace load	20.000 - 25.000 kW
Power consumption for pig iron with 1% Si	Abt. 2000 kWh per metric ton
Coke consumption (85% Fixed C), dry basis	350 - 400 kgs
Electrode paste	5 - 10 kgs
Down-time	2 - 5 %
Labour man-hours per ton	1.0 - 1.5

Presently the plant is being expanded with two 50 MVA ELKEM furnace units scheduled for completion towards the end of 1963. It is expected that the total annual capacity of the six furnaces will then reach 700 - 750.000 tons.

At Matanzas in Venezuela the large integrated iron and steel plant planned and built by Innocenti, Milan, was started up in 1961. Here nine 33 MVA ELKEM units are being put into operation. This state-owned enterprise is founded on the famous Cerro Bolivar "Iron Mountain", said to be the world's richest iron ore body so far discovered.

Other recent additions to the furnace family are two 18 MVA furnaces for Israel Steel Mills, and a 13.2 MVA furnace which Elektrokemisk A/S have designed for the Consolidated Mining and Smelting Company of Canada Ltd., in Kimberley, British Columbia.

Early 1962 an 18 MVA ELKEM furnace for the smelting of sintered beach sand concentrate was started up by Nisso Steel Mfg. Co. Ltd., Hachinohe, Japan.

5. PREPARATION OF RAW MATERIALS

As in the blast furnace operation progress has been made in raw materials preparation also for electric pig iron smelting. Also for electric furnace smelting the lump sizes of the charge components and the content of fines and dust are important for the furnace performance. Careful control with lump size and elimination of fines by screening are now standard practice with all larger electrothermic plants.

Systematic control of lump size has improved charge porosity and gas distribution. This provides a wider reaction and smelting zone in the electric furnace as well as smoother descent of the charge. Self-fluxing sinter eliminates calcination of raw limestone and dolomite by electric power. Apparently the self-fluxing sinter has increased chemical reactivity which is reflected in higher CO_2 content in the furnace gas. Also the self-fluxing sinter is supposed to lower the formation temperature of the slag in the furnace, whereby reduced temperature in the reaction zone has been established.

6. PREREDUCTION

In addition to the physical charge preparation by screening and agglomeration, the electric pig iron process is even more drastically improved by thermal and chemical pretreatment. Hereby a new process step has to be adopted - prereduction. Prereduction may be introduced in addition to sintering, or combined with agglomeration.

Different research institutes and private companies have attempted to develop prereduction. Independent groups in U.S.A. and Canada, and also groups in Japan, have worked intensively for improving the electric iron ore reduction. The object has been to make the process competetive with the conventional blast furnace in areas mainly supplied with thermal power. Comprehensive tests have been made with the Strategic-Udy process using a rotary kiln for preheating and prereduction, followed by electric smelting with a special technique. This process is based on the late dr. Marwin Udy's inventions. The Udy process facilitates selective reduction of complex ores and allows the use of fine-grained charge. Further, the process is well suited for direct production of semi-steel with medium or low carbon content.

Independently, Elektrokemisk, have undertaken research and development work on preheating and prereduction, and a summary of the methods used and some results obtained will be given here.

7. SHAFT PREHEATING

The simplest way to improve the performance is to preheat the complete charge in shafts installed directly above the electric furnace. In Elektrokemisk's Research Station, at their ferro-alloy smelter at Fiskaa Verk near Kristiansand in South Norway, a number of pilot plant shafts and a commercial-size prototype shaft have been built. A pilot shaft for a capacity of 500 to 1000 kgs of charge per hour is

erected directly above an electric furnace. Here the complete charge is heated counter-currently in a stream of hot combustion gases. Fuel oil or CO gas from the electric furnace is burnt with a controlled quantity of air and the hot gases are passed through a bed of charge in the shaft.

A considerable number of tests has been made with different iron ore and sinter charge. Reduced power consumption and increased production are obtained, not only due to the sensible heat in the charge, but also due to more indirect reduction. (exothermal formation of CO_2 by gas reduction), in the electric furnace:

Table 2.

Ore	% Fe	Cold charge			Hot charge		
		% CO_2	kgs Fixed C per metric ton	kWh per metric ton	% CO_2	kgs Fixed C per metric ton	kWh per metric ton
Magnetite Lump Ore	56	9	295	2350	23	84	1800
Self-fluxing sinter	54	14	308	2080	41	286	1580

8. ORE/CARBON PELLETS

Iron ores quite frequently are available as fines or as concentrates from ore dressing plants, while raw coal fines represent the cheapest source of carbon. These raw materials can be agglomerated together to produce charge briquettes or pellets for electric smelting.

Elektrokemisk's Research Division has during the last five years, conducted comprehensive tests with agglomeration, prereduction and smelting of charge pellets.

The preferred method is to pelletize ground ore and coking type coal with a binder. The pellets are produced on an inclined rotating disc, and the raw, soft pellets hardened by storage or drying. The hardened pellets are sufficiently strong for transport and handling within the plant limits. The charge pellets with addition of correction materials are heated counter-currently in a shaft by a stream of hot gases. Hereby the pellets are baked hard by carbonization of the coal, forming a strong carbon bond in the hot pellets. The hydro-carbons and hydrogen in the coal are distilled, and 10 - 30 % of the oxygen in the iron ore is removed in the shaft. The red-hot, prereduced pellets are continuously discharged and fed directly to the electric furnace below.

Due to the intimate contact between ore and coal in the pellets, and the content of volatiles in the coal, prereduction is obtained at temperatures far below the fusion point of the pellets. The charge pellets make a porous, reactive charge with excellent smelting properties. The favourable chemical reactivity is reflected in the high CO_2 content in the electric furnace reaction gas. This indicates a high proportion of indirect reduction - as in the blast furnace. In the Fiskaa pilot plant Elektrokemisk have operated test runs on ore/carbon pellets with magnetite as well as hematite iron ore, the following results being obtained:

Table 3.

Iron Ore	% Fe	Coal	% Fixed C	% CO_2	kgs Fixed C (per metric ton of pig iron)	kWh (per metric ton of pig iron)
Syd-Varanger	64	Longyear	50	30	290	1350
Algerie	56	Pocahontas	74	41	260	1270

In conventional pig iron plants concentrates are agglomerated by sintering in a separate, expensive plant where the ore is heated to incipient fusion and thereafter cooled for screening and transportation. In the new ELKEM process the pelletized charge is baked and prereduced simultaneously in simple shafts directly above the electric furnace which received the hot, partly reduced pellets. This new technique simplifies the agglomeration plant by combined agglomeration, preheating and prereduction. Hereby the charge is conditioned for the electric furnace smelting with considerably reduced power consumption and higher pig iron production.

9. ROTARY KILN

A mixture of iron ore, limestone and coke (or raw coal) is heated to about 1000°C in rotary kiln, whereby reactions between iron oxides and carbon is started, without fusion of the charge. The kiln product is transferred hot to the electric furnace in insulated containers.

The prereduction kiln is of the same type as used in other industries, for instance for burning of Portland cement clinker. These kilns are mechanically strong and have a long life. By placing thermo-couples through the kiln lining the temperature may be accurately controlled, so as to make sure that the working temperature is below the softening point of the charge. Thereby the cumbersome formation of rings is avoided. CO gas produced from reaction between iron oxides and carbon in the charge is burnt above the charge bed in the kiln by air supplied in controlled quantities through ports in the kiln shell. This supplies heat for the iron ore reduction.

Raw coal is a preferred reducing agent for kiln prereduction. By feeding raw coal through special scoop feeders directly through the kiln shell, an instantaneous carbonization of coal takes place due to the contact between the coal and the hot charge in the kiln. Hereby ring formation on the kiln lining is avoided even with strongly caking coals. This type of coal charging sideways into the kiln liberates volatiles from the coal which burns with oxygen in the kiln and supplies additional heat of combustion for the prereduction and preheating of the charge. Many types of raw coal produce char of high chemical reactivity, advantageous for high rate of reduction in the kiln.

By combustion of all CO gas formed in the kiln and electric furnace as well as volatiles from the coal, 50% or more of the oxygen in the ore may be removed by prereduction in the kiln. Preheating and prereduction decreases power consumption drastically with corresponding increase in the iron production. In Fiskaa's pilot plant test with high-grade ore from Algerie and Labrador, power consumption figures in the range of 900 - 1300 kWh have been obtained. With low-grade silicious ore, power consumptions in the range 1500 - 1800 kWh are typical.

For industrial use of the combination rotary kiln/electric furnace, the kiln would have to be placed on unreasonably high foundations if the hot charge should be transferred directly to the electric furnace charge openings.

The practical arrangement on a large scale, therefore, is to place the rotary kilns on normal foundations at ground level, discharge the hot prereduced material into a surge bin and transport in insulated containers to the electric furnace feed bins.

10. NEW INDUSTRIAL INSTALLATIONS

Preheating in rotary kiln with transfer of hot feed has already been in operation since 1958 in four 13.5 MVA ferronickel furnaces belonging to S.A. Le Nickel at their New Caledonia plant. A description of the plant and operation in New Caledonia has been published in Journal of Metals, March 1960.

The smelting technique adopted in this large plant, which now consists of five electric furnace units, originates from three smelting test campaigns at Elektrokemisk's Research Station.

An additional ferronickel furnace will soon be started up in Brazil by Morro do Nickel S.A.

In the pig iron field Rudnici I Zelezara SKOPJE in Jugoslavia will instal seven 34.5 MVA ELKEM furnaces, each with a rotary kiln. Here a low-grade chamosite ore, limestone and raw lignite coal will be heated in F.L. Smidth rotary kilns with scoops for feeding the lignite directly through the kiln shell. Despite the very low grade of the ore, the CO gas produced in the kilns and electric furnace and hydro-carbons and other volatiles from the lignite coal will cover the heat requirements for drying and heating of the charge in the kilns as well as partial reduction of ore and calcination of limestone.

Sinai Manganese Corporation have recently ordered a rotary kiln and 13.2 MVA ELKEM electric furnace for extraction of pig iron and ferromanganese from low-grade iron manganese ore in Egypt.

In Portugal a 13.2 MVA ELKEM pig iron furnace installed five years ago for conventional pig iron smelting is now being rebuilt for shaft prereduction of ore/carbon pellets. Presumably this plant will be in operation within the end of 1962.

In Venezuela, Corporacion Venezolana de Guayana will try the Strategic-Udy process on furnace No. 9. The furnace plant is now being equipped with a rotary kiln and the electric furnace adopted for the process in cooperation with Stratmat Ltd., Koppers Inc. and Elektrokemisk.

11. FUTURE TRENDS

Electric pig iron smelting is a special iron ore reduction process used and under installation in seventeen different countries. The electric furnaces are used not only in small iron works, but also in integrated iron and steel works of intermediate size with 300.000 - 700.000 tons annual capacity. The obvious fields for electric smelting of iron ore are areas in the world where coking coal of suitable quality for production of metallurgical quality coke is not available, while electric power such as water-power or cheap thermal power is at disposal.

The electrical smelting process has undergone refinement and technical advances in the last few years. The original conception of electric smelting was to supply the thermal requirements of the process from electrical energy and the chemical requirements from carbonaceous material. The present trend is to substitute carbonaceous material or other fuels for a portion of the thermal

requirements previously supplied entirely by electricity. This procedure has been a natural development. As the demand for larger and larger electric reduction units developed, the size of the furnaces grew almost in direct proportion. As the electrical load per furnace increased, the complexity, cost and power demand of the electrical systems continued to increase.

To reduce the electrical thermal load and lessen power consumption, operating procedures were modified to pretreat the raw materials, by preheating and/or partially prereducing, before charging them into the smelting furnace.

By reduction of the power consumption and increase in furnace unit capacity, the pig iron process may gradually achieve a more important part of the new pig iron production capacity, perhaps mainly by expansion to countries and areas which have not so far developed steel industry.

The great tolerance of the electric furnace with regard to quality of iron ores and reducing agents will justify electric smelting for new pig iron plants. Each project has to be examined very carefully with testing of the raw materials concerned to find the cheapest solution with regard to installation and operating costs.

Table 1.

	Number of furnaces in operation	MW	Number of furnaces under construction	MW	Total number of furnaces	Total MW
Canada	1	10.0			1	10.0
Egypt			1	10.0	1	10.0
Finland	1	10.0			1	10.0
India	2	20.0			2	20.0
Israel	1	14.5	1	14.5	2	29.0
Italy	5	42.0			5	42.0
Japan	2	19.5			2	19.5
Norway	5	110.0			5	110.0
Peru	2	20.0			2	20.0
Philippines			2	29.0	2	29.0
Portugal	1	10.0			1	10.0
Spain			1	6.5	1	6.5
Sweden	4	40.0			4	40.0
Switzerland	1	8.5			1	8.5
Venezuela	4	88.0	5	110.0	9	198.0
Yugoslavia	3	30.0	7	182.0	10	212.0
	32	422.5	17	352.0	49	774.5

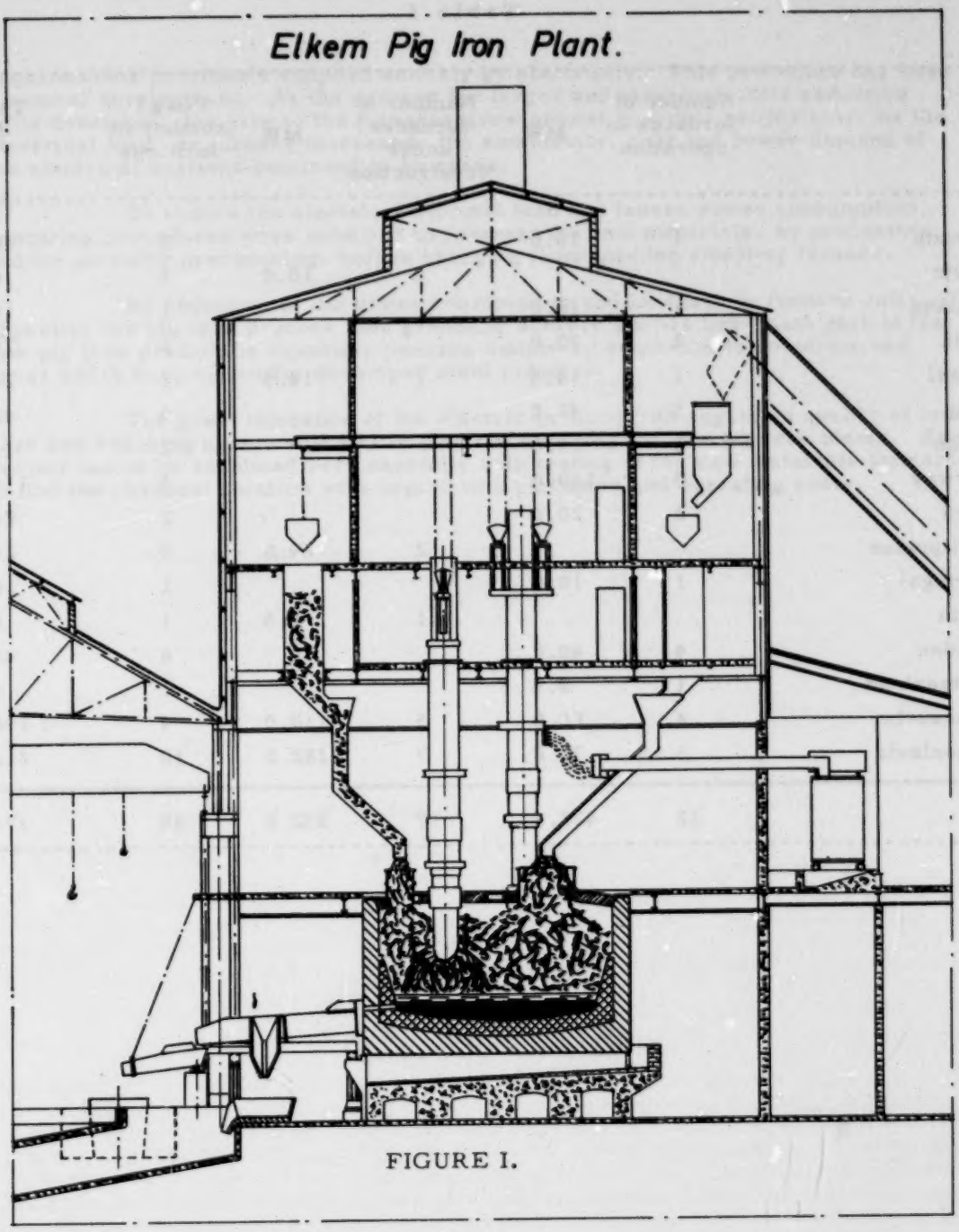

FIGURE I.

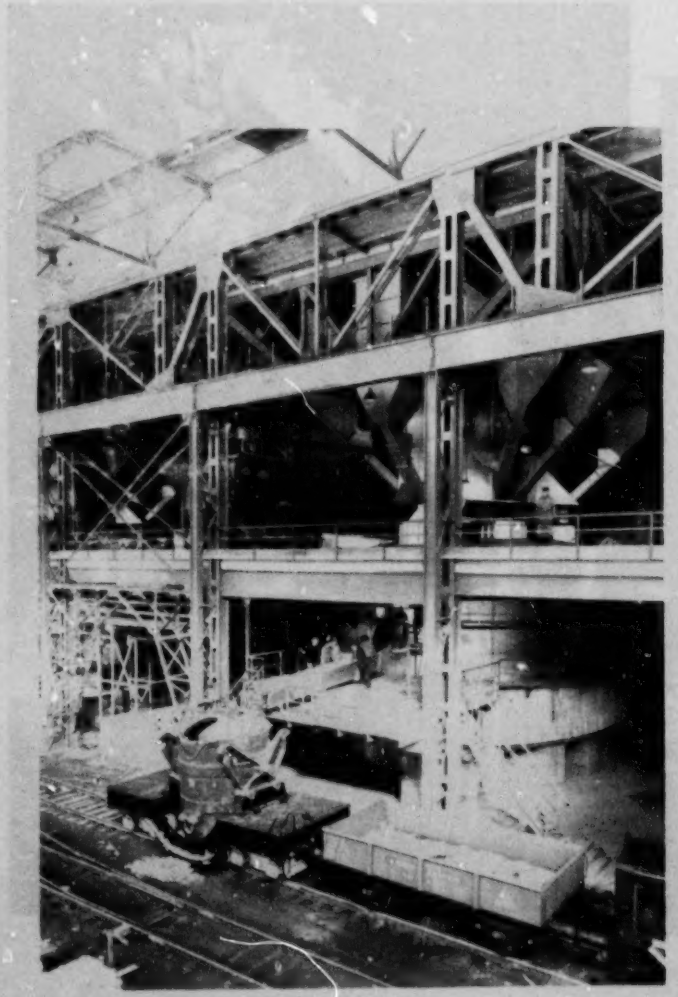

Fig.2 - From Norsk Jernverk, Mo i Rana, Norway

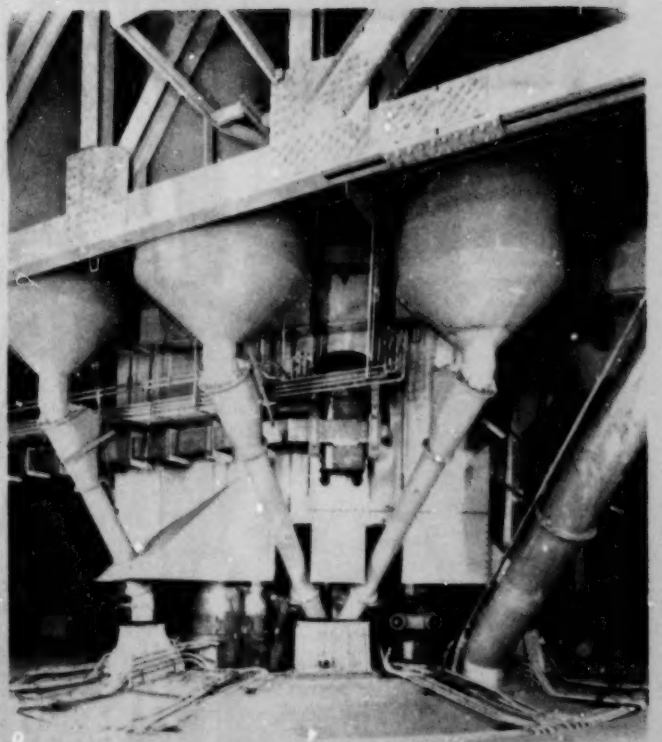

Fig.1 - From Bremanger Smelteverk, Svelgen, Norway

Fig.3 - From Corporacion Venezolana de Guayana, Matanzas

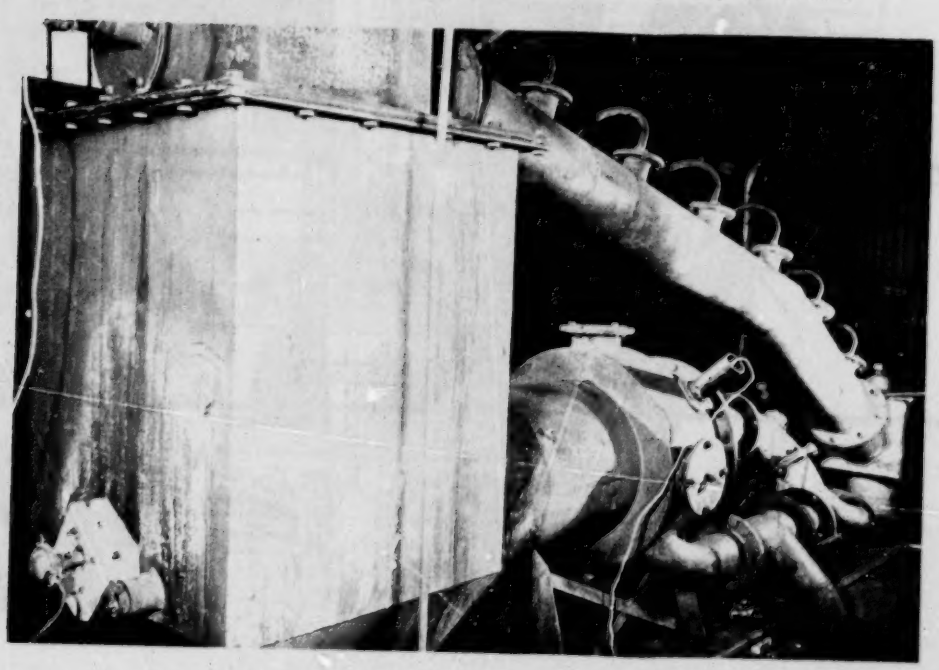

Fig.4 - Pilot Preheating Shaft, Elektrokemisk A/S, Fiskaa Verk, Norway

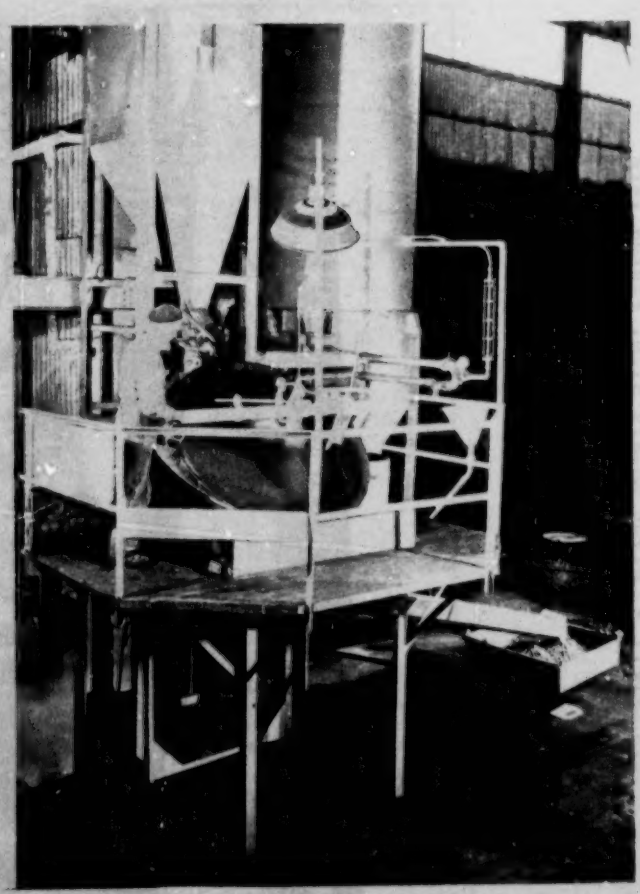

Fig.6 - Pelletizing Plant at Fiskaa Verk

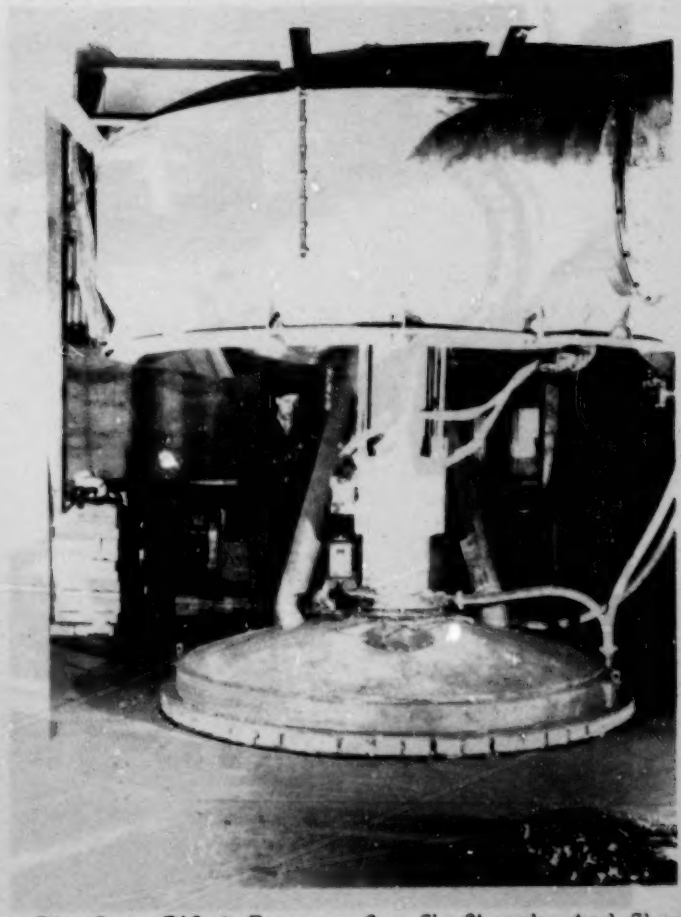

Fig.5 - Pilot Furnace for Shaftpreheated Charge

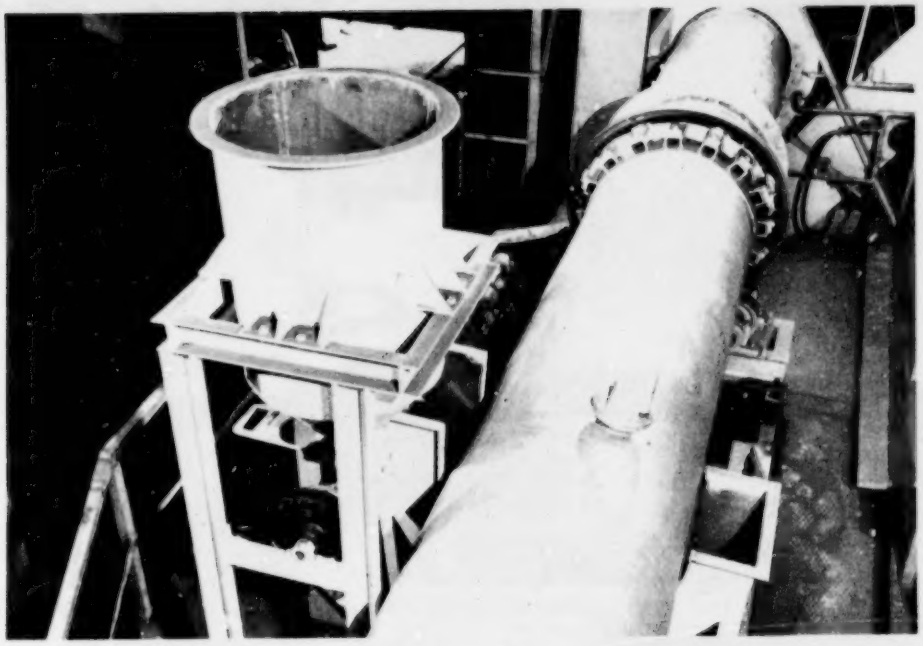

Fig.7 - Pilot Rotary Kiln, Fiskaa Verk

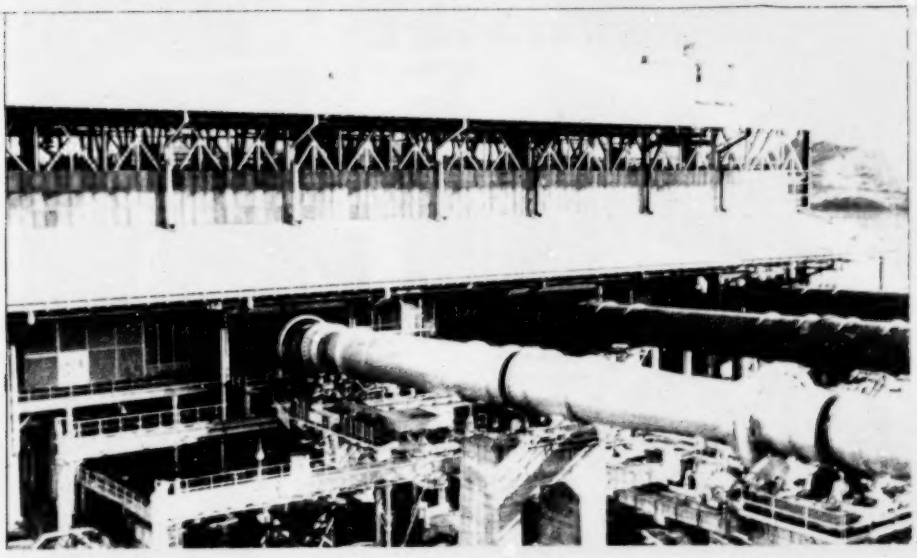

Fig.8 - From Ferronickel Plant in New Caledonia

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SUMMARY

Agenda Item: D.8.2 Norway

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By Frederik C. COLLIN,
Director of Research,
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SUMMARY

ELECTRIC SMELTING OF IRON ORES FOR LESS DEVELOPED AREAS

by

Fredrik C. Collin

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Oslo, Norway

The present status of pig iron smelting in the conventional blast furnace is referred to. The average capacity for blast furnace units in operation today is 500-1000 t/d in Western Germany and USA. Blast furnace performance has been improved the last years by raw material preparation, particularly sintering of the ore.

Mechanically strong, lumpy metallurgical coke is required for blast furnace operation. In many countries and areas of the world coal suitable for production of metallurgical coke is not available. In some cases ores containing TiO_2 and low-grade siliceous ores which cannot be concentrated economically rules out the use of blast furnaces. Electric pig iron smelting has solved the problems of pig iron production from off-grade raw materials.

The electric pig iron process was developed for commercial use in the Scandinavian countries and is now installed or under adoption in 17 countries. A total furnace capacity of 775 MW is already in operation or being installed.

The modern electric furnace for pig iron furnace is designed for loads between 10 and 40 MW, supplied with three Söderberg self-baking electrodes and circular furnace pot. The charge is fed from over-head bins which automatically keep the furnace filled with charge by gravity feed system. Performance

data for the state-owned Norwegian plant in Mo i Rana are:

Furnace load	20 - 25 MW
Power consumption for pig iron with 1% Si	2000 kWh per metric ton of pig iron
Coke consumption	350 - 400 kgs
Electrode Paste	5 - 10 "
Down-time	2 - 5 %
Labour man-hours per ton	1.0 - 1.5

The large integrated iron and steel plant erected at Matanzas in Venezuela is equipped with nine ELKEM pig iron furnaces which are successively being started up in 1962.

Raw materials preparation by screening of ore, coke and fluxes and production of self-fluxing sinter have improved the electric pig iron furnace performance. However, a much more drastic reduction in power consumption and increase in productivity are achieved by preheating and prereduction of the ore. In the paper a description is given of several different methods developed on pilot plan scale the last years. The simplest approach is to preheat the complete charge in the charge bins above the electric furnace. By preheating an increase in production of 25 - 30% has been obtained. Preheating and some prereduction is established by shaft heating of ore/carbon pellets. The pilot tests indicate saving in electric power equivalent to 50% increase in production per kWh. The use of rotary kiln for preheating in connection with the ELKEM electric furnace has been used since 1958 in production of ferronickel in New Caledonia and will now be adopted also for pig iron smelting in new plants at Skopje in Jugoslavia and in Egypt.. Raw coal is a desired reducing agent for kiln prereduction. The coal is carbonized in the kiln and the volatiles liberated utilized for preheating and prereduction of the ore in the kiln. Kiln pretreatment will increase the production per kWh with 100% or more, depending on the raw material situation.

The great tolerance of the electric pig iron process with regard to iron ore and carbon makes this process particularly interesting for many of the less industrially developed areas throughout the world. Off-grade ores and coals may be utilized economically for iron and steel production.

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CONFÉRENCE DES NATIONS UNIES
SUR L'APPLICATION DE LA SCIENCE ET DE LA TECHNIQUE
DANS L'INTÉRÊT DES RÉGIONS PEU DÉVELOPPÉES

Point de l'ordre du jour : D.3.2

Senegal

PROBLEMES SOULEVES PAR L'ISOLEMENT DES LIGNES ELECTRIQUES A HAUTE TENSION, EN BORDURE DE MER, DANS LES CONDITIONS CLIMATIQUES DU SENEGAL OCCIDENTAL

Par A. BERNOS,
Ingénieur Civil des Mines,
Directeur de la Compagnie Sénégalaise
des Phosphates de Taïba

Les mémoires rédigés à l'intention de la Conférence des Nations Unies sur l'application de la science et de la technique dans l'intérêt des régions peu développées sont des documents de travail. Ils sont publiés tels qu'ils ont été présentés et les assertions et opinions qu'ils contiennent sont celles de leurs auteurs.

NOTES

1. Les mémoires choisis pour être présentés en séance générale pourront être obtenus à la Conférence dans les langues officielles suivantes des Nations Unies: anglais, espagnol, français et russe.

2. Les mémoires choisis pour être présentés en séance spéciale pourront être obtenus à la Conférence dans l'une seulement de ces langues officielles.

3. Les résumés qui ont été rédigés pour tous les mémoires par les auteurs de ceux-ci pourront être obtenus à la Conférence dans les langues officielles suivantes des Nations Unies: anglais, espagnol, français et russe.

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Problèmes soulevés par l'isolement des lignes électriques à haute tension, en bordure de mer, dans les conditions climatiques du Sénégal Occidental.

par A. BERNOS, Ingenieur Civil des Mines, Directeur de la Compagnie Sénégalaise des Phosphates de Taïba.

1 - CARACTERISTIQUES de la LIGNE -

1-1 L'alimentation en courant électrique des exploitations de la Cie Sénégalaise des Phosphates de Taïba est assurée par une ligne 90 KV à un terne d'une longueur de 100 Km en antenne.-

La puissance absorbée, intégrée sur 10 minutes est de l'ordre de 7.000 KW. La section des cables de transport est de 288 mm2.-

Le schéma ci-après, précise le tracé de la ligne entre DAKAR et TAIBA.-

La ligne part du poste situé auprès de la centrale d'E.E.O.A. dans l'agglomération de DAKAR-et quitte la ville en suivant l'autoroute et la route DAKAR-RUFISQUE.-

Entre DAKAR et BARGNY la ligne longe la côte Sud de la presqu'île du Cap Vert. Ce tracé a été retenu pour protéger la ligne de l'influence des vents dominants de direction N-NW qui se chargent d'embruns au passage de la barre sur la côte Nord. Dans toute cette zone la ligne est donc soumise à l'influence de la mer quelle que soit la direction du vent. Expérimentalement, on a reconnu que l'influence de la mer, par suite de ces vents dominants, au point de vue pollution et corrosion, se faisait sentir jusqu'à près de 7 km. de la côte Nord. L'influence de la côte Sud est beaucoup moins importante tout au moins au voisinage de DAKAR et de la presqu'île du Cap Vert.-

Entre RUFISQUE et BARGNY, la ligne passe à proximité d'une cimenterie. Au delà de BARGNY, la ligne s'éloigne de la côte et l'influence marine diminue progressivement.-

1-2 C'est en fonction de ces conditions difficiles que des isolateurs spéciaux ont été retenus pour l'équipement des chaînes sur le tronçon de ligne en bordure de la mer.-

Les chaînes d'isolateurs se présentent comme suit :

1-2-1 du poste de DAKAR (pylône n° 1) jusqu'au pylône n° 138,(soit 40 km environ) près de SEBIKOTANE, situé à 5 km. de la côte Sud et à 8 km.de la côte Nord.-

Les chaînes comportent 8 éléments, type capot et tige pour bord de mer, en porcelaine Durelcer (dénomination CTB: 2471.).

Les caractéristiques des isolateurs sont les suivantes:

- diamètre ..... 247 mm.
- pas ..... 170 mm.

- tension de contournement à sec ..... 80 KV.
- tension de contournement sous pluie ... 44 KV.

Les caractéristiques de la chaîne sont les suivantes :

- nombre d'éléments 6
- longueur totale de la chaîne d'alignement, pince incluse ..... 1,24 m.
- tension de contournement à sec ..... 421 KV.
- tension de contournement sous pluie ... 200 KV.

1-2-2 Du pylône 139 jusqu'au poste de TAIBA, les chaînes sont constituées de 8 éléments du type capot et tige, en verre trempé. (CTV 254 de SEDIVER).-

Les caractéristiques des isolateurs sont les suivantes:

- diamètre ..... 254 mm.
- pas ..... 130 mm.
- tension de contournement à sec ..... 65 KV.
- tension de contournement sous pluie ... 45 KV.

Les caractéristiques de la chaîne sont les suivantes :

- nombre d'éléments 8
- longueur totale de la chaîne ..... 1,26 m.
- tension de contournement à sec ..... 407 KV.
- tension de contournement sous pluie ... 310 KV.

2 - INCIDENTS d'EXPLOITATION -

2-1 Les travaux d'équipement du tronçon DAKAR-THIES ont été terminés le 6 Août 1959.

La ligne DAKAR-TAIBA a été mise sous tension nominale le 20 Décembre 1959.-

2-2 Incidents

2-2-1 Le premier incident est survenu le 27 Janvier 1960 à 4h.35. Après disjonction de la ligne, et 3 essais sans résultat de remise sous tension, la ligne a été consignée jusqu'à 7h10. La ligne a été remise sous tension à ce moment sans intervention du personnel de la ligne.

2-2-2 La période d'exploitation s'étendant de Décembre 1959 à Juillet 1962 a donné lieu à de multiples déclenchements pendant la saison sèche, c'est-à-dire de Janvier à fin Juin.-

La durée de ces déclenchements a été extrêmement variable. La remise automatique sous tension était en général impossible

et les interruptions de courant subies par l'exploitation ont varié de quelques minutes à plusieurs heures.-

2-2-3 Tous les déclenchements sont survenus pendant la nuit entre 22 h et 8 heures et plus particulièrement entre 1 heure et 7 heures.-

2-2-4 A quelques exceptions près, ces incidents n'ont pas eu d'origine explicable par des coups de foudre, des surtensions internes ou des causes mécaniques, sauf un provoqué par un nid d'oiseaux. Le service a généralement pu être repris sans intervention des exploitants sur la ligne.-

2-2-5 A signaler que pendant ces mêmes périodes annuelles, les lampes à induction "Balisors" équipant la zone balisée au droit de l'hydrobase de Bel-Air, cessèrent de fonctionner.-

2-2-6 D'autre part, le conducteur de terre s'est rompu en Février 1962 au droit du pylône 33. L'examen des blocs de raccordement a permis de constater une fusion partielle (passage d'une forte intensité due vraisemblablement à un coup de foudre) mais aussi des corrosions importantes des brins d'almélec attribuées à un couple électrolytique Fer-Aluminium provoqué par l'atmosphère humide et saline.

Des visites effectuées de Février à Juillet 1962 ont montré que les corrosions précitées se multipliaient et se développaient rapidement.-

Aucune trace de corrosion, par contre, n'a été relevée sur les câbles de transport aluminium-acier de 288 mm2.-

2-3 Influence des conditions météorologiques -

Dans la région de DAKAR, la saison des pluies s'étend sensiblement du 1er Juillet au 15 Octobre. En dehors de cette période, les pluies sont pratiquement inexistantes.-

Le rapprochement des conditions météorologiques et de la statistique des déclenchements montrent que ceux-ci ont lieu en saison sèche, la nuit, c'est-à-dire aux heures où le point de rosée est susceptible de se former et lorsque le vent est faible.-

3 - OBSERVATIONS et ESSAIS sur PLACE -

Les observations effectuées sur place se sont concentrées sur la partie de ligne en bord de mer, du pylône n° 1 au n° 138, et ont porté sur les points suivants :

3-1 Observations auditives de la ligne sous tension au cours de la journée.

Dans certaines zones, un grésillement était perceptible au droit des pylônes, témoignant la présence d'effluves sur les isolateurs.

3-2 Observations visuelles, au cours de la nuit, de la ligne sous tension, avec enregistrements photographiques.

L'observation a porté sur le degré d'intensité des effluves sur les chaînes à différentes périodes. Pratiquement, sur toute la zone bord de mer, il a pu être constaté des effluves. Au delà du pylône 158, les effluves sont de plus en plus faibles.-

3-3 Visite de la ligne hors tension et examens des chaînes d'isolateurs qui ont permis de déceler :

- la pollution des isolateurs
- les traces d'amorçage

En plus de ces examens, il a été procédé au changement des chaînes d'isolateurs et à l'adjonction d'éléments à certaines chaînes en place.

3-4 Les résultats des observations effectuées sur la section comprise entre le pylône n° 1 et le pylone n° 158 mettent en évidence ce qui suit :

3-4-1 Toute la portion de ligne en bord de mer est sujette aux effluves.

3-4-2 Les effluves ne se manifestent que dans certaines conditions atmosphériques (humidité importante et point de rosée atteint).

3-4-3 Les effluves disparaissent après nettoyage des isolateurs et réapparaissent environ un mois plus tard et parfois moins.-

3-4-4 Lesmodifications des chaînes d'isolateurs n'ont pasmis en évidence d'amélioration sensible.-

De même les chaînes équipées d'isolateurs T 254 verre et celles équipées d'isolateurs CTEM semblent effluvées avec autant d'intensité, toutes choses égales par ailleurs.-

3-4-5 En conclusion, l'observation des effluves n'apporte aucun élément déterminant, car il ne permet ni de délimiter les zones critiques, ni de trouver une solution de remplacement. Il faut noter toutefois que la présence d'effluves sur les isolateurs n'implique pas forcément l'amorçage de la chaîne surtout si les effluves sont uniformément réparties.-

L'observation de la répartition des effluves le long de la chaîne est plus instructive que l'observation qui consiste à noter uniquement l'apparition ou l'absence d'effluves.-

3-5 L'examen des traces d'amorçage sur les chaînes est beaucoup plus probant et permet de délimiter des zones critiques et principalement celles comprises entre les pylônes suivants :

- n° 1 à 10
- n° 28 à 45
- n° 69 à 95

Par contre, il n'est pas constaté d'influence de la position de la chaîne (ancrage ou alignement) concernant le nombre d'amorçages.-

3-6 On peut remarquer que sur toutes les chaînes suriso-lées (9 CTV, 7 et 8 CTB.) il n'a été constaté aucune trace d'amorçage.

Cependant, l'expérience a été de trop faible ampleur pour qu'on en tire une conclusion. En effet, l'expérience ne porte que sur 15 chaînes, sur un total de 642 chaînes équipées de 6 isolateurs CTB..

3-7 Les constatations faites sur des chaînes d'isolateurs CTB. type ancrage, montrent que toute la surface extérieure des isolateurs est recouverte d'une fine couche de poussière peu adhérente. Par contre, la surface intérieure est tapissée d'un dépôt présentant une certaine épaisseur et relativement adhérent. (s'enlève à l'ongle, mais résiste au doigt).

Il n'a pas été fait d'examen analogue sur des chaînes d'isolateurs en verre.-

4 - ESSAIS en LABORATOIRE -

4-1 Trois séries d'essais ont été effectuées en laboratoire en vue de contrôler la tenue et les caractéristiques des isolateurs pollués.-

Deux chaînes de 6 isolateurs CTB. pollués, prélevées sur le pylône d'alignement n° 12, ont été expédiées avec précautions. A la réception en laboratoire, la pollution superficielle externe avait partiellement disparu du fait du transport, alors que la couche de poussière à l'intérieur de la cloche était intacte.-

4-2 Un essai a été effectué, au Laboratoire Central des Industries Electriques, sur deux isolateurs en vue de déterminer la variation de la tension de contournement en fonction de l'état hygrométrique de la couche de poussière.-

Cet essai a montré que la tension de contournement pouvait diminuer de moitié lorsque la condensation était importante.-

4-3 Une série d'essais a été effectuée par le Laboratoire sur une chaîne de 6 isolateurs CTBM.-

4-3-1 Un contrôle a été effectué sur tous les éléments pour s'assurer qu'il n'y avait pas de perforation de la porcelaine.-

4-3-2 Une analyse de la pollution a montré que la poussière prélevée sur les isolateurs contenait une forte proportion d'alcalin et d'alcalino-terreux,
soit 2,6% de CaO, 1,8% de K2O et 3,3% de Na2O

4-3-3 Un essai comparatif à sec et sous condensation, d'une chaîne polluée et d'une chaîne propre, ont montré un abaissement important de l'isolement de la chaîne polluée par rapport à celui de la chaîne propre. Cet abaissement d'isolement est beaucoup plus important dans l'essai avec condensation que dans l'essai à sec. Cependant, les tensions de contournement mesurées en Laboratoire restent nettement supérieures à la tension de service.-

Cette constatation peut s'expliquer par le fait que les conditions d'essais en Laboratoire sont plus favorables que les conditions locales et qu'une partie de la pollution superficielle a été enlevée.-

4-4 La Compagnie Sénégalaise des Phosphates de Taïba, a placé sur la plage de N'BORO, à 100 m. environ du rivage, sur un poteau de 6 à 7 mètres, deux isolateurs :

- un CTBM 247 L en porcelaine
- un CTV 252 en verre

A la suite d'une exposition d'un mois, ces isolateurs ont été fortement souillés et la galvanisation des capots a été attaquée, des traces métalliques ont été trouvées sur la porcelaine et le verre.-

5 - ENSEIGNEMENTS des ESSAIS -

Les observations et essais précédents montrent que :

5-1 les incidents de la ligne ont pour cause certaine la diminution importante d'isolement provoquée par de la condensation sur les chaînes d'isolateurs pollués.-

5-2 Il ne se dégage aucune solution qui permette de supprimer à coup sûr les déclenchements de la ligne.-

6 - SOLUTIONS au PROBLEME de POLLUTION -

6-1 Les expériences effectuées dans les réseaux étrangers montrent que le problème de la pollution n'a pas encore reçu de solution universelle et que chaque cas particulier est un cas d'espèce.-

6-2 Le réseau 60 KV. et 150 KV. en bord de mer de l'Energie Electrique du Maroc est celui dont les conditions d'exploitation se rapprochent le plus de celles de la zone DAKAR-TAIBA.-

Les résultats des experiences effectuées sur ce réseau, appliquées au cas de la ligne DAKAR-TAIBA, conduiraient à ajouter deux éléments aux chaînes équipées de 6 CTX. 247.-

Il faut remarquer, par ailleurs, qu'E.E.M. utilise des isolateurs à pas long (205 mm.) CTBX 247 L, alors que la ligne de DAKAR est équipée d'isolateurs CTX. 247 K à pas court (170 mm.). Il est possible, mais non certain, que l'augmentation de la longueur du pas de la chaîne ait une influence favorable. Seuls des essais permettraient de la vérifier. E.E.M. n'a pas essayé l'isolateur à pas court et il n'y a pas eu d'essais comparatifs.-

D'autre part, au MAROC, les ancrages ont toujours été équipés de chaînes d'isolateurs CT 254 fortement surdimensionnées (correspondant à 10 éléments pour 90 KV.).-

L'adjonction des deux isolateurs CTBX à toutes les chaînes des pylônes n° 1 à 138 reviendrait à près de 7 millions CFA. Le remplacement des chaînes d'ancrage équipées en CTBX par des chaînes équipées de 10 éléments CTV 254 et l'adjonction de deux ou trois éléments CTBX sur les chaînes d'alignement reviendrait également à près de 7 millions CFA.-

6-3 Dans certains réseaux, on procède au lavage périodique des isolateurs.-

En France, ce nettoyage a lieu hors tension, aux USA, en Suède et semble-t'il en URSS, le lavage a lieu sur la ligne en service.-

A DAKAR on a procédé à partir de Mars 1961 à un lavage manuel hors tension. La fréquence de un nettoyage tous les deux mois s'est avérée insuffisante et il a fallu passer au nettoyage mensuel.-

Un nettoyage complet des isolateurs hors tension revient à près de 500.000 fr;CFA pour la portion de ligne comprise entre les pylônes n° 1 et 158 et provoque une interruption de fourniture de 12 h.

6-4 Il serait peut-être possible de remédier aux déclenchements par suite de la pollution des isolateurs en recouvrant les isolateurs d'une couche de graisse au silicone. Cette application nécessite un nettoyage préalable et doit se répéter au moins tous les deux ans, et dans certaines conditions tous les ans.-

Le coût d'une application serait voisin de 7 millions de f. CFA.-

L'essai n'a pas eu lieu.-

6-5 Il est possible d'envisager le remplacement des isolateurs CTBT par des isolateurs d'un autre type.- Actuellement, aucun type d'isolateurs n'a été reconnu comme susceptible de convenir dans tous les cas de pollution. Il serait nécessaire d'effectuer des essais prolongés sur place pour déterminer le type d'isolateur adequat.-

Dans l'état actuel de nos connaissances, il semble que les chaînes constituées d'éléments CTV 254 se comportent mieux en bordure de mer que celles constituées d'éléments CTBT 247 M, mais aucune confirmation décisive n'a pu encore être fournie.-

7 - CONCLUSIONS -

7-1 En s'appuyant sur les expériences menées dans différents pays, il est possible de conclure :

- qu'il n'y a pas de panacée au problème de la pollution des isolateurs.-
- que certaines conditions appliquées dans certains cas ne peuvent, sans expérience préalable, être

étendues à d'autres cas.-

- que les essais en laboratoire ne permettent pas, pour le moment, de définir, à priori, avec certitude les caractéristiques optimales des chaînes d'isolateurs.-

- que des résultats satisfaisants ont été obtenus dans certains réseaux après essais de diverses solutions dans les conditions réelles d'exploitation.-

En conséquence, il a paru préférable, avant de prendre une décision, d'effectuer divers essais sur la ligne dans les conditions d'exploitation normales.-

7-2 Deux types d'essais ont été effectués :

7-2-1 - Essais de surisolement des deux types de chaînes équipant actuellement la ligne, dans les limites acceptables pour maintenir une distance d'isolement suffisante en cas d'inclinaison de la chaîne. (50 cm. minimum à la masse pour une inclinaison de 50°). Ils ont été essayés en alignement et en ancrage des chaînes comportant 8 et 9 CTB. et des chaînes avec 10 éléments standard en verre. Ces essais n'ont pas été concluants.-

7-2-2 - Lavage manuel périodique des isolateurs.- Cette mesure permet effectivement de remédier aux déclenchements, mais son application est onéreuse et provoque des interruptions de service très gênantes pour l'exploitation.-

7-3 - Deux autres types d'essais sont envisagés :

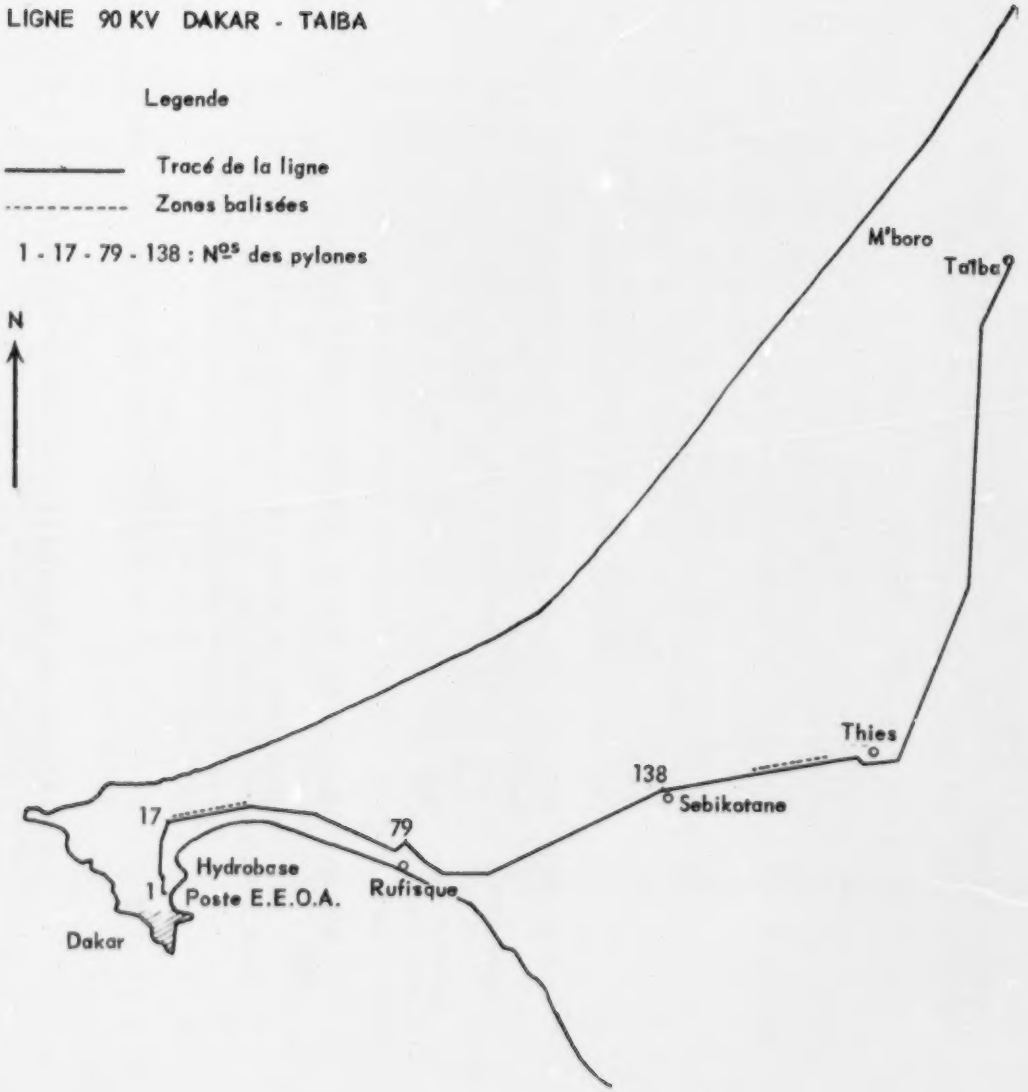
7-3-1 - Essais de types nouveaux d'isolateurs.-

Quelques types d'isolateurs ont été mis au point récemment par les fabricants, mais n'ont pas reçu la sanction d'ouvrages exposés au phénomène de pollution.-

7-3-2 - Lavage sous tension.- Deux méthodes ont été étudiées :

Lavage par arrosage : cette méthode pose le problème de l'alimentation en eau de qualité constante et de son transport en terrains accidentés et semble, à priori, peu pratique.-

Lavage à sec : par insufflation de poudres spéciales avec une lance à air comprimé. L'appareillage nécessaire va être approvisionné et sera mis à l'essai pendant la campagne 1963.-



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SUMMARY

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Senegal

INSULATION PROBLEMS ON HIGH-TENSION POWER LINES ALONG THE SEA-SHORE UNDER THE CLIMATIC CONDITIONS OF WESTERN SENEGAL

By A. BERNOS,
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Tafba

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

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INSULATION PROBLEMS ON HIGH-TENSION POWER LINES ALONG THE SEA-SHORE UNDER THE CLIMATIC CONDITIONS OF WESTERN SENEGAL

D.3.2.

By
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MANAGER OF THE SENEGAL PHOSPHATE COMPANY, TAIBA

SUMMARY

The Senegal Phosphate Company's plants are supplied with electric power by a triple-conductor 90 kW overhead line about 100 km. in length.

2. After leaving Dakar, the line runs for about 40 km. close to the sea. This section was, therefore, fitted with type CTBM 247 M porcelain insulators, while the rest of the line has type CTV 254 glass insulators.

3. When the line was put under load in December 1959, there were frequent failures, causing serious inconvenience in operating the plant, which runs continuously.

4. Observations up to the present have shown that:

(a) Failures were confined to the section running close to the sea.

(b) Failures were due to lowered insulating capacity caused by atmospheric moisture on the insulators.

(c) Such failures occurred only during the dry season, from January to the end of June.

(d) They occurred at night and mainly between 1 and 7 a.m. when atmospheric conditions favoured the formation of dew.

5. Laboratory tests confirmed a serious reduction in insulating power in dirty porcelain insulators when the air was damp.

6. No satisfactory answer to the problem having been found, the Taiba company made the following tests on the line:

(a) extra insulation on some of the chains, which were observed frequently

(b) cleaning insulators by hand, with power off.

7. Only the second method turned out to be satisfactory, but it had serious drawbacks - high cost of cleaning and long breaks in supply.

8. The extra insulation gave no positive results. It seemed however, that the CTU 254 glass insulators behaved better on the section near the sea than did the CTBM 247 M porcelain type.

9. In view of these not very encouraging results, the Company proposes to undertake further tests.

(a) fitting special insulators recently put on the market by makers, but not yet thoroughly tested in practice.

(b) coating insulators with silicone grease.

(c) cleaning with power on, by blowing on special powder with compressed air. Washing under power has been abandoned for the time, because of the difficulty of providing and transporting water of suitable quality.

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FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: D.11.1

India

INDUSTRIAL DEVELOPMENT-SCIENTIFIC AND TECHNICAL FACTORS IN CHOICE OF FERTILISERS AND RAW MATERIALS

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UNITED NATIONS CONFERENCE
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THE APPLICATION OF SCIENCE AND TECHNOLOGY
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Agenda Item : D : INDUSTRIAL DEVELOPMENT

D.11.1 : Scientific and technical factors in choice of fertilisers and raw materials.

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Introduction:

1. The importance of fertilisers for increasing crop yields is now accepted. Formerly, there was considerable controversy about the relative merits of manures and chemical fertilisers. The superiority of organic manures for maintaining better soil texture as well as its capacity to retain moisture is well-known. The physical effort involved in the collection of organic manures such as town refuse and compost, as well as the cost of their transport to the point of usage, however, set a limit to their application. The use of chemical fertilisers is therefore unavoidable if the growing world demand of food is to be met.

2. The crop yield per acre has been used often for comparing soil fertility. Such a comparison between two areas may give rise to misleading conclusions, if they have not been under cultivation for the same period of time. For example, the yields per acre of cereals in India would appear very low compared to those in Europe or in the United States, if the effect of centuries of cropping and inadequate manuring of Indian soils is overlooked. The comparison does help, however, to bring out the urgent need for application of chemical fertilisers to such soils for stimulating higher yields per acre currently as well as for building up soil fertility on a long-term basis.

3. The three essential plant nutrients are nitrogen, phosphorus and potassium. In terms of paddy the application of a pound of fertiliser nitrogen increases the yield by about 10 lbs., whereas for a pound of phosphorus it is lower, at about 7 lbs. The response to the application of phosphorus is slow, but it is well-known that unless the availability of phosphorus in the soil is maintained, the response to added nitrogen begins to fall. Thus, it is necessary to step up the

application of phosphorus along with nitrogen, the preferred proportion being 1 of N to 1 of P_2O_5. Potassium is important particularly for garden crops. Other plant nutrients such as calcium, sulphur, and trace elements are usually available in the soil; whenever any particular deficiency develops, it can be corrected by the application of compounds containing these elements along with nitrogenous fertilisers.

Types of Fertilisers:

4. By-product ammonium sulphate from coke ovens of steel works was recognised early as a source of fertiliser nitrogen. It is obtainable in yields of the order of 30 lbs. per ton of steel. When the demand for ammonium sulphate increased beyond its availability as a coke oven by-product, materials based on synthetic ammonia were developed for use as fertilisers. The first such fertiliser introduced in Norway was calcium nitrate. This was followed by synthetic ammonium sulphate and subsequently by other nitrogenous fertilisers including calcium cyanamide, ammonium nitrate, urea, and ammonium chloride. A recent innovation is the use of anhydrous ammonia by direct application of the gas to the soil. It is claimed that when injected six inches below the freshly broken surface, ammonia is completely retained by the moisture present in the soil, and that by this method the cost of application of fertiliser nitrogen is reduced considerably. Similarly, it is suggested that large compact areas can be supplied with nitrogenous fertilisers at low cost by adding ammonia to irrigation water.

5. Formerly, fertiliser mixtures were used for supplying simultaneously more than one plant nutrient. The mixtures were prepared by compounding chemicals containing nitrogen, phosphorus and potassium, that were produced separately. A recent tendency is to produce compounds that contain more than one plant nutrient. The principal products of this type are ammonium phosphate and nitro-phosphate. The relative proportion of nitrogen and phosphorus in the final product can be adjusted to the desired ratio by admixture of ammonium sulphate or urea to these products and processing the mixture into granules. Salts of potassium or other plant nutrients can also be incorporated.

6. Ammonium sulphate is a free flowing fertiliser and, therefore, very convenient whenever manual application is necessary. This explains its popularity in tea gardens where fertiliser must be applied near the roots of standing plants. The nitrogen content of commercial fertilisers is given below in Table I.

TABLE I

Fertiliser		Content of Nitrogen Per cent.
Ammonium sulphate	... ...	20
Ammonium nitrate	... ...	33 to 34
Calcium ammonium nitrate	... (i)	20.5
	(ii)	26
Ammonium sulphate nitrate	...	26
Ammonium chloride	... ...	32
Urea	... ...	45

In different countries, the price of fertilisers to farmers varies from Rs.0.7 to 1.6 per kilogram of N in the form of ammonium sulphate. With the other fertilisers, Nitrogen is generally available at a lower price per kg., but some difficulties may arise. For instance, due to its hygroscopic nature, urea must be packed in a bag with an impervious lining and the entire contents of the bag used immediately after it is opened. Prilled ammonium nitrate is used extensively in Europe, but it is still not popular in tropical countries because of its hygroscopic character and also the risk of fire or explosion if it comes into contact with some organic material. The explosion hazard as well as the tendency of ammonium nitrate to cake in a moist atmosphere are removed by reducing the nitrogen content down to 20 per cent, by admixture with powdered lime. Even then the product is still not popular in India. Ammonium chloride may not be suitable for all crops but there is evidence that it is satisfactory for the cultivation of paddy and cocoanuts.

7. Agronomically, fertiliser nitrogen should be available to soils throughout the period of germination of the seed and its subsequent growth to a plant. For most crops the presence of ammoniacal as well as the nitrate form of nitrogen in a fertiliser is valuable because it provides both the immediate nitrate and deferred ammoniacal supplies of the nitrate. However, with paddy, ammoniacal nitrogen can be taken up directly; this explains the growing popularity of urea in rice cultivation. Products like ammonium nitrate or urea were introduced in the last decade when the high ruling price and occasional scarcity of sulphur gave rise to a desire to avoid its use. This tendency may not persist now because, in the first place, the world trend is towards the production of high analysis complex fertilisers. These require phosphoric acid for their production and the wet process based on sulphuric acid is still the cheapest method for producing phosphoric acid. The prices and availability of sulphur have also improved dramatically in the last few years with the appearance of France, Canada and Poland as suppliers of sulphur in competition to the USA.

Single and Triple Superphosphate.

8. Phosphate rock, of which $Ca_3(PO_4)_2CaF_2$ is the principal constituent, is the source of phosphatic fertilisers. Neglecting the fluorine radical, the molecular ratio of CaO to P_2O_5 varies from 3.4 to 4.2 according to the source of rock. In acid soils or wherever acidity is likely to arise from use of organic manure, finely ground rock phosphate may itself prove satisfactory. The more popular method is to obtain superphosphate by treatment of rock phosphate with acid in which the P_2O_5 is in the water soluble form, i.e., as monocalcium phosphate. Decomposition with sulphuric acid yields single superphosphate, with a P_2O_5 content of 16 to 19 per cent; with phosphoric acid the product obtained is triple superphosphate containing about 45 per cent P_2O_5. Use of triple superphosphate is often favoured on the ground that

the cost of transport will be substantially lower for handling the more concentrated product. For this reason, some countries in which deposits of phosphate rock as well as sulphur-bearing materials occur together, plan to produce and export triple superphosphate instead of phosphate rock. Since the investment for production of a unit of P_2O_5 is more than twice for triple superphosphate than for single superphosphate, the latter may remain the more acceptable fertiliser unless the savings on freight counterbalance the increased cost of production of triple superphosphate. The relative expenditure of foreign exchange per unit of P_2O_5 in the product will also influence the choice between import of phosphate rock or superphosphate by developing countries.

Nitrophosphates.

9. A large number of complex fertilisers grouped under the generic term Nitrophosphate are made, without using sulphur, by treatment of rock phosphate with nitric acid or a mixture of nitric and other acids, followed by neutralisation of the mixture with ammonia. In order to produce a freely flowing granulated fertiliser with good keeping qualities from this mixture consisting essentially of di-calcium phosphate, ammonium nitrate and calcium nitrate, it is necessary to remove from this mixture two moles of calcium nitrate per every mole of rock phosphate treated. This is done either by precipitation as calcium sulphate, calcium phosphate or calcium carbonate, or by crystallisation and separation of the calcium nitrate by cooling. In all these cases, the precipitated calcium remains in the final product; in the phospho-nitric process it also helps to raise its P_2O_5 content. The processes are flexible enough to permit the making of a final product containing any desired proportion of water soluble P_2O_5.

10. Nitrophosphate will be one of the products of the Trombay Fertiliser Factory. In order to ensure that the product of the Trombay Factory would be suitable for use in this area where the pH of soils varies from 6.5 to 8.5 and the main crops are paddy and sugarcane, a Government of India technical delegation visited Europe in 1960 to study the problems associated with the use of various forms of Nitrophosphate. The delegation noticed that two divergent views were held by experts in this field. According to one view, if a high C/N ratio is maintained in the soil through the application of organic manures, then mono-calcium and di-calcium phosphates are equally effective and the choice would depend on which was cheaper. Thomas slag is popular in Italy for this reason. It was claimed that plants take up phosphorus from the soil solution, in which the optimum concentration of phosphate ions does not exceed 1.2 mg. per litre. Since the phosphate ion concentration to be obtained with di-calcium phosphate is substantially higher than this value, there is no need to increase it by applying water soluble phosphates. The delegation noted that in conformity with this view, in France a premium in price is allowed per unit of P_2O_5 when it is in the form of di-calcium phosphate.

Several other authorities in Europe, however, hold the opposite view that for short-term crops in particular an adequate proportion of water soluble P_2O_5 is essential for ensuring rapid early growth of crops. This requirement was stated to be of special importance in areas where phosphate reserves in the soil have still to be built up. The Indian delegation agreed with this view and recommended as a safe approach to the problem that Nitrophosphate applied to paddy should contain between 30 and 40 per cent of water soluble phosphate.

Raw Materials for Ammonia Synthesis.

11. Ammonia is the first step in the production of nitrogenous fertilisers. Ammonia is made by catalytic synthesis under pressure from a gas mixture consisting of hydrogen and nitrogen in the ratio of 3:1. Liquefaction of air followed by distillation gives Nitrogen. For Hydrogen, there are many processes and the choice depends on the availability of raw materials and the cost of production. Electrolytic hydrogen or processes based on coal gas, natural gas, petroleum refinery gases, coal, coke or petroleum naphtha are the usual sources.

Partial oxidation of the fuels with air or oxygen yields carbon monoxide and hydrogen. The carbon monoxide is then oxidised with steam to carbon dioxide, and the latter is removed by scrubbing with water under pressure. The use of oxygen is preferred because it is available as a by-product in the separation of nitrogen or in the production of electrolytic hydrogen. In fact, in order to utilise the oxygen fully, it is now customary to adjust the proportion of electrolytic hydrogen and hydrogen derived by partial oxidation of liquid or gaseous hydro-carbons.

12. As stated earlier, the choice of a raw material or process for hydrogen will be governed largely by the cost of its production. Coke was used quite commonly in the forties. Its use has, however, receded in recent years partly because it is becoming increasingly difficult to obtain adequate supplies of coal that yields coke oven gas as well as coke of satisfactory quality for gassification in the desired ratio. Also, the investment on plant and equipment is about 30 per cent higher than that for hydrogen from liquid or gaseous feedstocks. Electrolytic hydrogen is no longer popular partly because it is expensive and also because in most countries it is now considered unwise to use electricity for this purpose when several urgent demands for power compete with each other. Natural gas or petroleum refinery gases are preferred if they are available at a reasonable price. During the last few years, light petroleum naphtha has also become the preferred raw material in many parts of the world, wherever surplus of naphtha is available at a favourable price.

It is sometimes argued that whenever surplus naphtha is available in a country as it is likely to be in India for the next few years, all such naphtha should be earmarked for production of nitrogenous fertilisers. The reason put forward in support of such a plea is that ammonia production based on naphtha will ensure a low price for fertilisers even if they have to be transported over long distances. While making this claim, it is assumed however that on a thermal equivalent basis the price of naphtha would be equivalent to that of other carbonaceous raw materials available in the country, and freight rates on naphtha will be low so as to permit its use in the production of synthesis gas at considerable distances from the Refineries. Unfortunately these conditions are not existent in India.

The price of coal per tonne at the pit-head is about one-fourth of the price of naphtha, without excise duty, at the Refineries. The freight rates on coal are the lowest, whereas naphtha must be transported at the higher rates applicable to dangerous petroleum. Also, naphtha can be used readily to produce organic chemicals as well as fertilisers, but not coal or coke. It would therefore appear that naphtha is not necessarily the only raw material that will produce fertilisers at a low price, and that under circumstances described above, coal will be equally satisfactory at some locations.

Changing Trends in Fertiliser Production in India:

13. The changing trends in production and raw materials have been reflected in the development of the nitrogenous fertiliser industry in India. The first unit was established at Belagula in Mysore in 1939, based on electrolytic hydrogen, with a capacity for production of only 25 tonnes per day of ammonium sulphate. Planning for the second unit at Alwaye in Kerala began in 1943. It was felt at that time that forest wood would be the cheapest carbonaceous material in Kerala. Therefore, the unit was designed to operate on hydrogen from gassification of wood. When it started in 1947, the factory had a capacity for ammonium sulphate equivalent to 10,000 tonnes N per year, employing gypsum. A rapid increase in labour costs for collection and transport of wood led to the use of electrolytic hydrogen for the first expansion in capacity of 10,000 tonnes N per year. Also, a further expansion in capacity was contemplated on the basis of electrolytic hydrogen. In the meanwhile, it appeared that naphtha would soon become available in the country at a reasonable price. The plans were therefore changed so as to eliminate altogether the use of hydrogen obtained by gassification of wood, and raise the capacity to 60,000 tonnes N per year, with electrolytic and naphtha based hydrogen in the proportion of 1 to 5. The first phase of expansion will be completed this year with an increase in the capacity up to 30,000 tonnes N and closure of the wood gassification plant. A capacity of 60,000 tonnes N

will be achieved in 1964 when the expansion programme is fully implemented, the products being ammonium sulphate, ammonium phosphate and ammonium chloride.

The first really large fertiliser factory, set up at Sindri, started production in 1951. Its initial capacity was for 70,000 tonnes of N as ammonium sulphate, based on hydrogen from coke, and gypsum. Initially coke was obtained from merchant coke ovens. Two years later, the factory set up its own coke ovens so that coke as well as coke oven gas became available for the production of hydrogen. When the plan was made in 1955 for expansion of the production capacity at Sindri to 115,000 tonnes N, inclusive of some urea and ammonium sulphate-nitrate among the products, there was a corresponding increase in the coke oven capacity. The desired ratio between coke and coke oven gas could not be maintained, however, because of non-availability of the desired quality of coal in adequate amounts, and consequently production at Sindri has been affected. Various suggestions have been made for restoring the balance. These include the production of hydrogen either directly from coal in slagging generators or from naphtha.

A decision to set up a large fertiliser factory at Nangal in the Punjab was taken in 1954. At that time, the possibility that naphtha could be used as a source of hydrogen for ammonia synthesis had not become apparent in India; nor did the prospect of transporting coal from Bihar, a distance of several hundred miles. appear attractive. The construction of a 400 megawatt hydro-electric power project at nearby Bhakra had already commenced at that time. It was, therefore, decided that the Nangal Factory should undertake integrated production of heavy water as well as fertilisers from electrolytic hydrogen. The capacity for fertilisers was for 80,000 tonnes N in the form of calcium ammonium nitrate (20 per cent N). The Factory started production in 1961.

Although production of fertilisers from petroleum refinery gases at Trombay in Bombay has been under consideration since 1955, the decision to set up a factory was taken only in 1959. This unit will have a capacity of 90,000 tonnes N, as urea and nitro-phosphate, and hydrogen will be obtained from refinery gases and naphtha in approximately equal proportions. It is expected that when this factory comes on stream in 1964, its cost of production of ammonia will be the lowest in the country.

Fertiliser Production Programme in India.

14. In 1961 India produced 134,500 tonnes N mainly in the form of ammonium sulphate, calcium ammonium nitrate, ammonium sulphate-nitrate (double salt), and urea. The target

for production of nitrogenous fertilisers for the last year of the Third Five Year Plan, i.e., 1965-66, was set initially at one million tonnes of N. The programmes of expansion of existing units as well as of new units for which firm commitments have been made, show that a capacity of at least 0.84 million tonnes N will be available by 1965-66. The details of all these units, including the types of products proposed and the raw materials that will be used are summarised in Table II (pages 9 & 10). The data show that ammonium sulphate, urea and ammonium phosphate are the most favoured fertilisers, and that coal and coke will continue to be used as raw materials for their production.

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TABLE II

PROGRAMME OF FERTILISER PRODUCTION IN INDIA

BY 1965-66.

Name of Unit	Raw Material	End Products	Production capacity in Tonnes N/ year.
I. Existing Units (inclusive of Expansion)			
1. Mysore Chemicals And Fertilisers Ltd., Belagula, Mysore.	Electrolytic Hydrogen	Ammon-Sulph. ...	1,320
2. Fertilisers & Chemicals (Travancore) Ltd., Alwaye (Kerala)	Electrolytic Hydrogen and Naphtha.	Ammon-Sulph. ...	33,000
		Ammon-Phos. ...	21,000
		Ammon-Chloride...	6,000
3. Fertiliser Corporation of India, unit at Sindri (Bihar)	Coke and Coke Oven Gases.	Ammon-Sulph. ...	70,000
		Ammon-Sulph.-Nitrate ...	36,000
		Urea ...	11,000
4. Fertiliser Corporation of India, unit at Nangal (Punjab)	Electrolytic Hydrogen	Cal-Ammon-Nitrate ...	80,000
5. Sahu Chemicals Ltd. Varanasi (Uttar Pradesh)	Coke	Ammon-Chloride...	10,000
		Total ...	268,320

Name of Unit	Raw Material	End Products	Production capacity in Tonnes N/ year
II. Units under Construction and Design.			
1. Unit of Hindustan Steel Ltd. at Rourkela (Orissa)	Coke Oven Gases	Cal-Ammon-Nitrate...	120,000
2. East India Distilleries And Sugar Factories Ltd., Ennore (Madras)	Naphtha	Ammon-Phos. ...	16,500
3. Neyveli Lignite Corpn., Neyveli (Madras)	Lignite	Urea ...	70,000
4. Unit of the Fertiliser Corpn. of India at Trombay (Bombay)	Refinery Gases and Naphtha	Urea ...	45,000
		Nitro-Phos. ...	45,000
5. Unit of the Fertiliser Corpn. of India at Namrup, Nahorkatiya (Assam)	Natural Gas	Ammon-Sulph. ...	20,000
		Urea ...	25,000
6. Unit of the Fertiliser Corpn. of India at Gorakhpur (Uttar Pradesh)	Naphtha	Urea ...	80,000
7. Andhra Sugars Ltd. at Kothagudum (Andhra Pradesh)	Coal	Urea ...	66,000
8. Parry & Co. Ltd. at Vishakhapatnam (Andhra Pradesh)	Naphtha	Urea ...	8,000
		Ammon-Phos. ...	72,000
		Total ...	567,500
	TOTALS OF I & II ...		268,320 Tonnes N/year (I)
			567,500 " (II)
			835,820 Tonnes N/year.

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D.11.1 Scientific and technical factors in choice of fertilisers and raw materials.

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SUMMARY

1. Fertilisers are required for increasing the productivity of land for obtaining greater yields of foodgrains and cash crops. The term 'fertiliser' is applied usually to products that contribute plant nutrients such as N,P,& K, as distinct from manures which also contain organic matter.

2. Fertilisers may provide either one or more plant nutrients. Nitrogenous fertilisers containing nitrogen alone are ammonium sulphate, urea, ammonium nitrate, nitro-chalk, ammonium sulphate-nitrate and ammonium chloride. Latterly, there is a growing tendency to use ammonia directly either as gas or as ammonia liquor. It is necessary to ensure that fertiliser nitrogen is available to soils throughout the period of germination of the seed and its subsequent growth to a plant. Among single nutrient phosphatic fertilisers are ground rock phosphate, single and triple superphosphate, di-calcium phosphate and basic slag. The choice will depend upon the price per unit of P_2O_5 available in the fertiliser.

3. Both the nutrients N & P are provided by mixed and granulated fertilisers or by complex fertilisers. Among the latter are mono and di-ammonium phosphate and nitro-phosphates. Nitro-phosphates may be produced in different forms and with varying proportions of water soluble P_2O_5. The need to avoid the use of sulphur in the production of phosphatic fertilisers that led to the development of Nitro-phosphates may not be equally urgent now.

4. Phosphate rock is the usual raw material for phosphatic fertilisers. It is available in many parts of the world but many countries also depend on imports. There is considerable controversy regarding the merits of single and tripe superphosphate and also on the effectiveness of water and citrate

soluble phosphates. In acid soils and for long standing crops, citrate soluble phosphates are satisfactory. For basic soils and short-term crops, water soluble phosphates are more effective. Response to phosphatic fertilisers is slower than that with nitrogenous fertilisers. It is, therefore, necessary to build up the phosphate content of soils. The ratio of added nitrogen to phosphorus in advanced countries often exceeds 1:1. In developing countries the demand for nitrogen develops more rapidly.

5. Production of synthetic ammonia is the first step in the manufacture of fertilisers. Synthesis gas consisting of nitrogen and hydrogen in the ratio of 1:3 is necessary for this purpose. Hydrogen is obtained from coke oven gas or as electrolytic hydrogen; it can also be made by chemical reactions employing natural gas, petroleum refinery gas, naphtha or fuel oil, or by gassification of coal, coke or wood. The choice depends on indigenous availability as well as on the price of the raw material.

6. The changing trends in types of fertilisers and choice of raw materials are reflected in the current fertiliser programmes in India. Gassification of wood will no longer be employed for the production of fertilisers. Electrolytic hydrogen as well as coke may not be used as raw materials for the production of hydrogen in new projects, because of high cost and unavailability. While refinery gases and naphtha will be used as raw materials to an increasing extent, coal will also be used. Ammonium sulphate, urea and ammonium phosphate appear to be the most popular fertilisers.

7. A summary of the existing and new fertiliser projects in the Third Five Year Plan is given in tabular form in Table II.

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